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EFFECTS OF PHOSPHATE MINERALIZATION AND THE PHOSPHATE INDUSTRY ON RADIUM-226 IN GROUND WATER OF CENTRAL FLORIDA

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
LAS VEGAS FACILITY
LAS VEGAS, NEVADA 89114

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Robert F. Kaufmann
James D. Bliss

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation and to promote development of controls necessary to protect the public health and safety. In-depth field studies of various radiation sources (e.g. nuclear facilities, uranium mill tailings, and phosphate mills) provide technical data for environmental impact statement reviews as well as needed information on source characteristics, environmental transport, critical pathways for population exposure, and dose model validation

Where possible in terms of programmatic priorities and available staff, the Office of Radiation Programs laboratories also provide technical assistance to EPA regional offices. In this technical assistance role, staff of the Las Vegas Facility were responsible for assessing the impacts of the central Florida phosphate industry on radiochemical quality of ground water. Available geologic, hydrologic, and water quality data were assembled and interpreted to determine what adverse impacts, if any, are attributable to the industry and to compare radiochemical quality of ground water in the study area to State and national conditions. Finally, recommendations were developed to mitigate adverse or objectionable situations in terms of preserving environmental quality and public health.

The reader should be aware that two rather diverse viewpoints surround this study and report. Some have considered the data base too limited to conclude that no widespread or significant contamination has occurred or is occurring. Therefore, extensive additional studies are essential. Others, particularly industry, consider the data and interpretation herein as confirmation that contamination has not occurred, that present practices and data collection requirements are adequate, and that more study and monitoring would be inefficient. The authors explicitly recognize this schism in that while the available data are analyzed and conclusions drawn, criticism as to adequacy and improvements are also clearly stated.

Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
Office of Radiation Programs

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EFFECTS OF PHOSPHATE MINERALIZATION AND THE PHOSPHATE INDUSTRY ON RADIUM-226 IN GROUND WATER OF CENTRAL FLORIDA

ABSTRACT

Principal U. S. phosphate production is from central Florida where mining, processing, and waste disposal practices intimately associate the industry with water resources. Available radium-226 data from 1966 and from 1973-1976 were statistically analyzed to characterize radium in the water table, Upper Floridan, and Lower Floridan aquifers. Mined and unmined mineralized areas and nonmineralized areas in the primary study area in Polk, Hardee, Hillsborough, Manatee, and De Soto counties were studied. Log-normal probability plots and nonparametric statistical tests (Mann-Whitney, Kruskal-Wallis, Kolmogorov-Smirnov, simultaneous multiple comparison) were used to analyze for central tendency, variance, and significant difference as functions of time, depth, and location.

Geometric mean radium-226 content of the water table aquifer in mineralized unmined areas is 0.17 pCi/l, with few observations exceeding 5 pCi/l. Compliance with the EPA drinking water standard for dissolved radium (5 pCi/l for radium-226 plus -228) is likely although confirmatory radium-228 data are needed. This is particularly so in areas containing monazite sands where thorium-232, the parent for radium-228, is elevated relative to other areas of central Florida. No significant difference exists in the radium content of the water table aquifer in mineralized (mined and unmined) areas versus nonmineralized areas, inferring that mining and mineralization have not caused a widespread and significant increase in the radium content of this aquifer.

Radium content of the Upper Floridan aquifer is poorly documented. For mineralized but unmined areas, 1 of 5 observations exceeds 5 pCi/l, compared to 1 of 10 in mined areas. Simultaneous multiple comparison at the 80 percent confidence level reveals significant difference between mined and nonmineralized groups, yet mean radium in nonmineralized areas exceeds that in

mined areas, implying no adverse marked change in radium-226 in the Upper Floridan aquifer as a result of mining and waste management. Log-normal probability plots of radium in the Lower Floridan aquifer for mineralized and nonmineralized areas are very similar, again indicating that phosphate mineralization or the industry is probably not a factor. Three separate populations are indicated with geometric means of 0.7, 3, and 10 pCi/l.

Radium in the Floridan aquifer in Manatee and Sarasota Counties is elevated relative to that in the water table and in other areas of Florida. The mean content for seven Manatee County wells was 4.52 pCi/l versus 1.23 pCi/l in three water table wells. Geometric mean radium content of the water table aquifer in Sarasota County is 15 pCi/l versus 7.5 pCi/l in the Floridan. Potential radium sources for the water table include shallow phosphate sediments and monazite sands whereas radium in the Floridan aquifer in this area may be related to mineralized water in the aquifer and to crystalline basement rocks or other strata unrelated to phosphatic zones of current economic interest.

The existing radium-226 data base is marginal in terms of number and spatial distribution of analyses, particularly for the water table and Upper Floridan aquifer. Time series data are nonexistent and study objectives and techniques for the past decade have been rather inconsistent. Therefore the data are not readily compared. No distinct temporal trend is apparent in comparing individual or grouped observations made in 1966 and those in the period 1973-1976. Local contamination associated with specific operations has occurred and is likely to continue as water development and mining expand. Natural variability in radium content of ground water complicates determination of background versus contaminated conditions and underscores the need for more intensive data collection as an integral part of water and land management.

SUMMARY AND CONCLUSIONS

1. Using available radium analyses for the period 1966 to 1976 from a study area located in Polk, Hardee, Hillsborough, Desoto, and Manatee Counties of central Florida, nonparametric statistical tests and graphical techniques were utilized to evaluate radium concentrations in three separate aquifer systems (water table, Upper Floridan, Lower Floridan), mineralized and nonmineralized areas, and two time periods: 1966 and 1973-1976. Geometric mean radium concentration in the water table aquifer in unmined, mineralized areas is 0.17 pCi/l compared to 0.55 pCi/l in mined areas. For the Upper and Lower Floridan aquifers, average concentratons of radium-226 are equal or higher in the control areas relative to mineralized or mining areas.

2. Assessment of dissolved radium-226 in the water table aquifer indicates that no significant differences (Mann-Whitney U test, α = .05) exist between areas impacted by mining and those with mineralization, but not yet mined. None of the radium-226 observations available in mined areas for the water table aquifer exceed 5 pCi/l.

3. Assessment of dissolved radium-226 in the Upper Floridan aquifer indicates significant differences (Kruskal-Wallis test, α = .05) between data from nonmineralized, mineralized (and mined) and mineralized, unmined areas. Using simultaneous multiple comparisons (α = .20), one pair has a significant difference. The nonmineralized data have higher radium levels than data from areas influenced by mining. Clearly, detrimental increase in radium in the Upper Floridan aquifer is not documented. Average levels for all Upper Floridan aquifer observations are higher than for those in the water table aquifer, and similar to that of the Lower Floridan aquifer.

4. Comparison of data from mined and nonmined but mineralized areas versus data from nonmineralized areas reveals that radium-226 in the Lower Floridan is not significantly different (Mann-Whitney U test, α = .05). In addition, graphical analysis of the data suggests that dissolved radium in the Lower Floridan may be made up of as many as three separate populations, the geometric means of which are 0.7, 3.0, and 10 pCi/l.

5. Radium-226 data collected in 1966 by the FWPCA and in 1974-1976 by the USGS from each of the three aquifers reveals no statistically significant difference (Kruskal-Wallis test, α = 0.05 and simultaneous multiple comparisons, α = 0.20) for the decade considered.

6. Incidence of occasional local contamination (laterally to distances of a mile and to depths of several hundred feet) is likely to continue as water development and mining expand. Contamination is generally poorly documented due in part to monitoring deficiencies. Hydrogeologic conditions favor entrance of contaminants to at least the water table and Upper Floridan aquifers. Potential contaminant sources include high dissolved radium in gypsum pond water and suspended radium in slime ponds. Entrance of contaminants into ground water can occur as a result of sinkhole collapse (or similar release) and seepage. Siting of waste disposal facilities in contact with limestone strata of the Hawthorn Formation, in particular, fosters contamination problems.

7. Radium-226 concentrations in ground water of Sarasota County, the secondary study area, are two orders of magnitude greater than in the primary study area for the water table and almost an order of magnitude greater for the Floridan aquifer. Radium in the water table aquifer is significantly greater in the coastal area as opposed to an inland area (Mann-Whitney U test, α = .05). Elevated (relative to Florida and national averages) radium-226 levels in both the Floridan and water table aquifers are a result of natural enrichment processes, probably related to radium-enriched, mineralized ground water deep under the central peninsula but at shallow depths in coastal areas, and dissolution of radium-226 from the Hawthorn Formation which crops out or is very near the land surface

in the western portion of Sarasota County. Monazite sands in the coastal area are a potential source of radium-228 in ground water which warrants further monitoring.

8. Hydrogeologic conditions in the area of phosphate mineralization are quite variable and can be favorable or unfavorable for waste disposal. The principal variables are the distribution and permeability of carbonate strata in the Hawthorn Formation and the degree of interconnection between the Upper and Lower Floridan aquifers. Disposal of acidic chemical processing effluent may induce solution and collapse of carbonate strata and thereby increase contamination. However, the data to support widespread occurrence of this phenomenon are scanty.

9. The radiochemical quality of water introduced to the Lower Floridan aquifer via recharge wells has only recently begun to be documented. Preliminary data from SWFWMD indicate that radium-226 levels are generally lower than those in the Lower Floridan aquifer. The occurrence of at least locally high natural concentrations of radium in the shallower aquifers requires close monitoring and reporting of such data so that the presence or absence of naturally contaminated water in a given mining operation is documented by site specific radiochemical data.

10. Three separate aquifers present in the study area require specific monitoring programs to determine baseline and subsequent conditions through the reclamation stage. Until recently there has been excessive reliance on use of existing water wells for monitoring water quality in the Lower Floridan aquifer. Data collection typically consists of single grab samples and diverse analytical procedures, both of which present major limitations to detailed definition of water quality impacts from the industry, particularly with respect to the water table and Upper Floridan aquifers.

11. From both temporal and spatial standpoints and in relation to commonly recognized objectives for monitoring, the existing radiochemical data base is not adequate. Baseline and contamined water quality in areas of

mineralization (with and without mining) is difficult to establish, particularly for the water table aquifer. Hydrologic and geologic data collected by industry largely precede mining and processing and thereby only partially document baseline conditions. Time series data are needed, analytical procedures should be standardized, and emphasis should be on sampling wells designed specifically for monitoring. From a public health study standpoint, existing radium-226 data are probably minimally adequate to determine the quality of public water supplies. Particularly in areas of phosphate mineralization and/or in areas containing monazite sands, limited radium-228 data should also be collected for private and public water supplies to confirm whether the EPA drinking water standard is being met.

12. Water budget studies are recommended to document seepage losses from gypsum ponds. Extensive ground-water studies by industry largely focus on the Lower Floridan aquifer and are designed to determine effect of withdrawal on the hydrologic system for purposes of justifying application for SWFWMD consumptive use permits. Past monitoring of the water table and Upper Floridan aquifers for contamination was minimal but the situation is improving, largely due to SWFWMD requirements.

RECOMMENDATIONS

IMPROVED WASTE DISPOSAL

Use of lined ponds for gypsum wastes should be required if such facilities are found to contribute significant radioactivity to ground water. Regardless, rainfall exceeds evaporation in Florida, and alternative water removal and/or recycling may become a necessary part of the control program to prevent the long-term formation and release of leachate from gypsum piles. The feasibility of neutralizing acidic wastes to reduce radium solubility and the potential for solution collapse of gypsum pond substrates should be investigated.

MONITORING

Review of recent discussion of ground water quality monitoring methodology (Todd et al., 1976) reveals four basic objectives of monitoring: ambient trend, source, case preparation, and research. There is little evidence that any concerted effort with respect to radiochemical contaminants has ever been put forth in any of the four types. Particularly lacking, considering the scale of the phosphate industry, are measurements of ambient spatial and temporal trends and deviations in relation to standards. Monitoring of effluent quantity and quality factors as potential sources of ground water contamination are also noticeably absent.

The reader is referred to extensive discussions by Todd et al. (1976) of the steps involved in implementing a ground-water monitoring program. Application and tailoring of the conceptual steps to the central Florida setting and the phosphate industry far exceeds the scope of this report. However, the meager knowledge now existing concerning the effects of the industry on shallow ground water quality is perhaps the most compelling reason to implement needed studies and related abatement programs in consonance with section 102(a), 104(a), 106(e), and 502(19) of the Federal Water Pollution Control Act (as amended) and sections 1424(e), 1442(a)(1), 1442(a)(4), and 1442(a)(5) of the Safe Drinking Water Act.

As discussed here, monitoring denotes a scientifically designed program of ongoing surveillance incorporating direct sampling, inventory of existing and potential causes of change, analysis of cause and effect with respect to water quality, and prediction of future change. Of key concern with respect to Florida phosphate mining and processing is long-term prediction of the extent, or at least the trend of radium contamination.

Recommended monitoring during the operation of a mine and related facilities includes measurement of water levels in piezometers and selected water wells, water sampling, geophysical measurements, and maintenance of material balances, particularly water. The reader is referred to Warner (1974) and Le Grand (1968) for information concerning the kind and location of sampling points, frequency of sampling, measurement of water levels and geophysical surveys. Borehole techniques and electrical resistivity (Merkel, 1972; Hackbarth, 1971; Stollar and Roux, 1975) are deemed particularly suitable for delineating zones of preferential contaminant migration and for selection of monitoring points.

WATER SAMPLING AND ANALYSIS

1. Radium-226 data should be routinely collected from the three principal aquifers in mineralized (mined and unmined) areas to ascertain temporal and spatial trends in water quality. Measurement of other parameters such as gross chemistry, pH, fluoride, and suspended/dissolved solids is also recommended. Concentrations of other radionuclides should also be investigated.

2. Wells should be repetitively sampled and a concerted effort should be made to resample wells used in previous studies. In this case, identical analytical procedures should be followed to reduce differences due to analytical techniques.

3. Sample collection and handling should emphasize field filtration followed by acidification. Analysis should be for dissolved and suspended radium.

4. Sampling of producing wells low in suspended solids is preferable. Monitoring wells and piezometers not in daily use should be pumped or bailed and allowed to settle shortly before sampling. Sampling, per se, should allow minimal suspended solids to be collected.

HYDROLOGY AND GEOLOGY

1. Analysis of lateral and vertical ground-water flow patterns in all principal aquifers should precede, accompany, and follow mining, waste disposal, and reclamation operations.

2. Water budget and material balance studies should be undertaken to confirm the magnitude of seepage from gypsum ponds. Where extensive seepage can be documented or where disposal areas are geologically unsuitable, corrective action in the form of lining or alternative siting is recommended.

3. Ground-water quality monitoring should be based on analysis of local hydrogeologic conditions and should place principal emphasis on the water table and Upper Floridan aquifers

4. Geochemical investigations are necessary to document the amount, kind, and distribution of radioactivity in overburden and matrix materials prior to and after mining and waste disposal. Predictions of radionuclide migration from disturbed soil profiles remaining after mining and reclamation should be made to assess future radionuclide content of shallow sediments and contained ground water. Kinetics of radium solubility under changed Eh and pH conditions in the subsurface are poorly known. The transport rate for radium in the vadose and saturated zones, taking into account dispersion and sorption, require much additional study relevant to the Florida phosphate situation.

5. Reasons for and mechanics of sinkhole collapse or other means whereby massive release of slimes and gypsum wastes to the subsurface should

be documented and corrective active taken, particularly considering the expansion of phosphoric acid production in Florida.

6. Stabilization of gypsum piles, in particular, also necessitates control of infiltration from precipitation in order to prevent leachate production and subsequent migration to nearby surface and subsurface water bodies. Techniques developed for moisture control in common sanitary landfills and for land disposal of toxic wastes should be investigated for their applicability.

DATA INTERPRETATION AND REPORTING

1. Applications for mining and processing and periodic interpretive written reports submitted by industry should detail monitoring programs and results and need for corrective action.

2. Periodic documented reports of the state of the environment should be prepared by appropriate State agencies based on results of industry data and other study programs conducted by the State or State/Federal cooperative efforts. Emphasis should be on confirmation of conditions predicted in DRI applications, maintenance or improvement of desired environmental conditions, and identification of short and long-term benefits and impacts stemming from phosphate extraction and related commitments of land and water resources.

PROBLEM DESCRIPTION

Major centers of production for domestic phosphorus are located in Florida, North Carolina, Tennessee and in the western states of Idaho, Montana, Wyoming, and Utah. Total U.S. production of marketable (beneficiated) phosphate rock in 1976 was about fifty million short tons, about eighty percent of which was from Florida (Stowasser, 1976). The principal area in Florida and the subject of this report is the land pebble mining district (Figure 1) which was selected for study because it is the principal existing and potential producing area in the State and therefore the scene of extensive mining, chemical processing of phosphoric acid, and land reclamation. Extensive ground-water development for irrigated agriculture, the phosphate industry, and municipal purposes is occurring in the region.

The multiplicity of Federal interests and actions in the Florida phosphate industry prompted the Council of Environmental Quality to request and fund preparation of an environmental impact statement under the auspices of Region IV of the U.S. Environmental Protection Agency (USEPA). This report is in direct support of the overall effort to document present and expected environmental impacts associated with phosphate mining and ore processing in central Florida. Other studies by the Office of Radiation Programs address other aspects including atmospheric releases from processing plants and indoor and outdoor radiation exposures associated with use of reclaimed phosphate lands for housing structures.

The U.S. Environmental Protection Agency (1976a) has issued regulations concerning the amount of radium in public water supplies. In terms of drinking water regulations, radium-226 is lumped with radium-228 and jointly the two must not exceed 5 pCi/l. While radium-228 is a beta emitter as opposed to radium-226, which is an alpha emitter, radium-228 has a chain of alpha-particle emitting daughters such that the gross alpha particle activity limit for drinking water is defined to include radium-228. Furthermore, if water

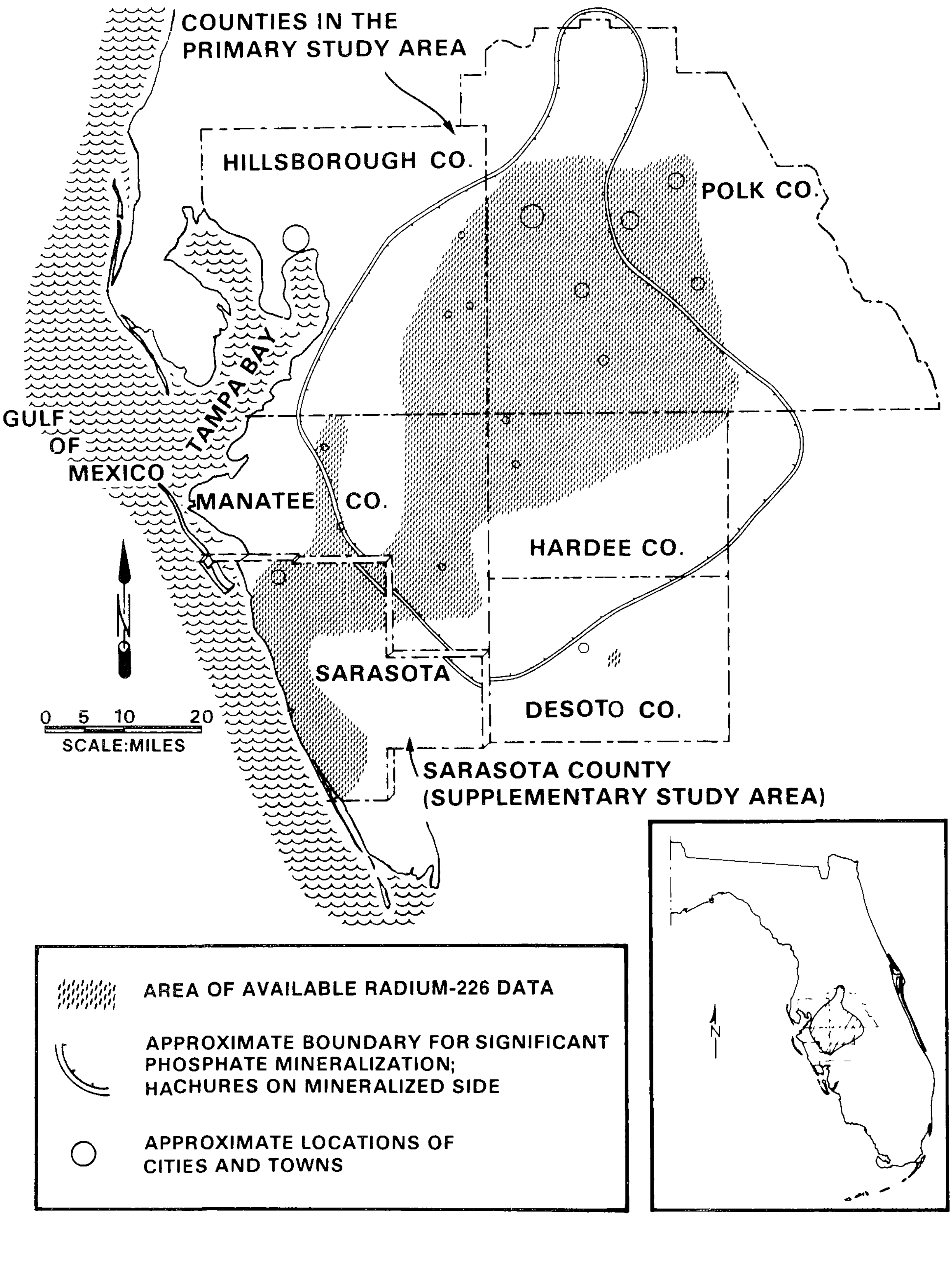


Figure 1. General location map.

contains greater than 5 pCi/l alpha activity, radium-226 must be determined. If radium-226 is greater than 3 pCi/l, then radium-228 must be determined. However, if other information suggests that radium-228 is present, States are recommended to determine radium-228 and/or radium-226 if gross alpha is greater than 2 pCi/l (USEPA, 1976a).

In the study area, land and water use patterns and management are closely related to the phosphate industry insofar as mining, beneficiation, and chemical processing have the potential to adversely affect ground-water quality through a variety of mechanisms. Radiochemical species naturally present can be concentrated and mobilized as a result of mining activity or waste discharge from mining, processing, or reclamation activities. Given this, the objective of this report is to document, using available data, hydrogeologic and water quality conditions as they passively or actively relate to the phosphate industry in west-central Florida. Secondly, there is a need to identify necessary additional studies and data collection efforts.

This report summarizes the hydrogeologic situation in a portion of central Florida as related to phosphate occurrence and, more importantly, to the potential for ground-water contamination from phosphate mining and processing. Also included is a brief review of the occurrence of radium in water. Existing radium (in water) data from central Florida are statistically analyzed to compare radium concentrations in ground water for 1) mineralized versus nonmineralized areas and 2) mining/processing areas versus mineralized but undeveloped areas. Monitoring efforts to date and resulting data base are evaluated and recommendations are made concerning needed improvements.

PREVIOUS AND ONGOING INVESTIGATIONS

Owing to the demands on ground-water resources imposed by the phosphate industry and other municipal and agricultural water users in central Florida, there has been greatly increased interest in the last decade to identify environmental impacts. Since 1973, State and regional agencies within Florida carefully reviewed applications for mining and other activities affecting the environment to determine if environmental, social, and economic impacts have been identified and to rule on the acceptability of such impacts (380.06(06), Florida Statutes). Known as Development of Regional Impact (DRI), the review process is somewhat analogous to an environmental impact statement and is initiated by the interests proposing development. Technical documents and development orders appurtenant to the DRI process constitute site-specific sources of available information concerning data collection, expected impacts, and mitigating measures. Numerous geologic and hydrologic investigations conducted in central Florida also constitute valuable resource material and are referred to as appropriate.

Water quality effects associated with the phosphate industry and areas of phosphate mineralization has been mentioned in reports by the Federal Water Pollution Control Administration (Shearer et al., 1966), Battelle Memorial Institute (1971), Datagraphics, Inc. (1971), U.S. Environmental Protection Agency (1973; Guimond and Windham, 1975), and most recently the U.S. Geological Survey (Irwin and Hutchinson, 1976). The principal radium-226 data upon which this report is based include the following: 1) Open file analyses from the U.S. Geological Survey (obtained from R. C. Scott, private consultant, Atascadero, California, formerly with the USGS and USEPA), 2) Scott and Barker's (1962) study of the distribution of radium in water throughout the country, 3) an FWPCA survey in 1966 (Shearer et al., 1966), 4)ground-water sampling by USEPA from 1973-1976, 5) ground water and surface water sampling by the USGS from 1974-1976 (Irwin and Hutchinson, 1976). The manner in which these various data bases are used is explained in the section on water quality.

Other studies include Osmond's (1964) summary review of the distribution of uranium and thorium in the rocks and water of Florida. Williams et al., (1965) presented gross alpha data for 280 untreated well water samples from Florida. This included 22 samples from 18 shallow wells in the central Florida phosphate district.

HYDROGEOLOGIC SETTING OF WEST CENTRAL FLORIDA

GEOLOGY OF CENTRAL FLORIDA

Geologic investigations of those portions of Polk and Manatee Counties of interest herein include U.S. Geological Survey quadrangle reports (Cathcart, 1963a, 1963b, 1963c, 1964, and 1966) and numerous cooperative studies by the U.S. Geological Survey in cooperation with the Florida Geological Survey (Peek, 1958; Pride et al., 1966; Stewart, 1966; and Robertson, 1973). (Note: Florida Geological Survey is now called Bureau of Geology.)

The stratigraphic sequence in the study area primarily consists of gently dipping carbonate bedrock overlain by a thin sequence of clastic and phosphatic sediments. Formational names, lithologic descriptions, thickness, and aquifer makeup are shown in Table 1. Generalized stratigraphic cross sections through the study area are shown in Figures 2 and 3. In most areas, the surface material consists of Pleistocene sands, commonly called terrace sands, containing varying amounts of organic debris. In southwest Polk and adjacent counties, these sands are underlain by the Bone Valley phosphorite unit, a complex assortment of reworked phosphatic clay, silt, and sand at least partly derived from the underlying Hawthorn Formation as a result of intense lateritic weathering and leaching (Cathcart, 1964). The lowest unit consists of a basal phosphatic conglomerate much enriched in phosphate (Hoppe, 1976) and usually part of the phosphate ore zone which is locally called matrix. The Bone Valley unit thins or is absent in northern and eastern Polk County but is prominent throughout much of southwestern Polk County and adjacent areas in Hillsborough, Manatee, DeSoto, and Hardee Counties. The gentle southerly dip (Cathcart and McGreevy, 1959) results in deeper burial in these latter areas.

Underlying the Bone Valley unit is a phosphatic, interbedded sequence of limestone, dolomite, sand, sandy clay, and gray clay known as the Hawthorn

TABLE 1. GEOLOGIC AND HYDROGEOLOGIC UNITS IN CENTRAL FLORIDA

GEOLOGICAL AGE	FORMATION		LITHOLOGICAL DESCRIPTION		THICKNESS (ft.)	AQUIFER	ROLE IN PHOSPHATE DEPOSITS
			UNWEATHERED	WEATHERED			
PLEISTOCENE	TERRACE DEPOSITS Qt		UNCONSOLIDATED QUARTZ SAND WITH ORGANIC DEBRIS	LOOSE QUARTZ SAND, SWAMP DEBRIS	0-65	WT[1]	NO DIRECT ROLE NOTED
PLIOCENE	BONE VALLEY FORMATION Tb	upper Tbu	RED & WHITE MOTTLED SANDY CLAY; GREY AND TAN SAND, CLAYEY; SCATTERED PHOSPHATIC NODULES INCREASING TOWARD BASE	WHITE SAND, TRACE OF CLAY WITH SCATTERED DULL WHITE PHOSPHATIC NODULES PARTICULARLY AT BASE	P[2]:0-25 M[3]:0-35 (totalTb)	WT	INTENSE LATERITIC WEATHERING USUALLY DEPLETED IN PHOSPHATE
		lower Tbl	SANDY, CLAYEY GREY & GREY GREEN PHOSPHORITE; NODULES SAND TO GRANULE SIZE, LOCAL BASAL PHOSPHATIC CONGLOMERATE	WHITE SAND, VESICULAR WITH DULL WHITE PHOSPHATE GRADING DOWNWARD TO GREY OR GREY-GREEN SAND CLAYEY OR SANDY CLAY WITH NUMEROUS NODULES,	P:0-35	UA[4]	BASAL CONGLOMERATE GREATLY ENRICHED IN PHOSPHORUS DURING INTENSE WEATHERING OF HAWTHORN PRINCIPAL ORE COMPONENT IN POLK CO.
MIDDLE MIOCENE	HAWTHORN FORMATION Th		OLIVE GREEN, GREY BROWN CLAYEY SANDSTONE WITH NODULES TO A BUFF, WHITE LIMESTONE WITH NODULES AT BASE. DOLOMITIZED	CALCAREOUS SANDY CLAY WITH BROWN OR BLACK PHOSPHATIC NODULES WITH POSSIBLE GRADATION TO LIME-STONE AT DEPTH	P:0-130 M:150-350	P:UF[5] M:UF or LF[6]	PARENT MATERIAL, IN PART, FOR BONE VALLEY:IRREGULAR UPPER SURFACE BECOMES IMPORTANT ORE IN MANATEE CO.
EARLY MIOCENE	TAMPA FORMATION Tt		LIGHT YELLOW, SANDY AND CLAYEY LIMESTONE; BROWN BLACK PHOSPHATIC NODULES MAY BE CLAYEY SAND	CALCAREOUS SANDY CLAY CONTAINING SCATTERED PHOSPHATIC NODULES	P:10-80 M:150-175	P:UF M:UF or LF	SOME RESIDUAL CLAY PRESENT FROM WEATHERING EVENTS WHICH ENRICHED ORE WHEN UPPER HAWTHORN ABSENT. NOT ORE
LATE OLIGOCENE	SUWANNEE LIMESTONE Ts		FOSSILIFEROUS CREAM OR TAN LIMESTONE; VERY SOFT GRANULAR DETRITAL	NEAR SURFACE OCCURENCE TENDS TO BE SILICIFIED	P:80-120 M:150-300	LF	NO DIRECT ROLE NOTED
LATE EOCENE	OCALA GROUP To		WHITE, GREY, CREAM OR TAN SOFT GRANULAR LIMESTONE OF HIGH PURITY; DOLOMITIZED ALSO SOFT, CHALKY	SILICIFIED TO HARD, GREY TO WHITE CHERT.	P:125-270 M:300-325	LF	NO DIRECT ROLE NOTED

[1]NONARTESIAN [2]POLK COUNTY [3]MANATEE COUNTY [4]UPPER MOST ARTESIAN [5]UPPER FLORIDAN ARTESIAN [6]LOWER FLORIDAN ARTESIAN

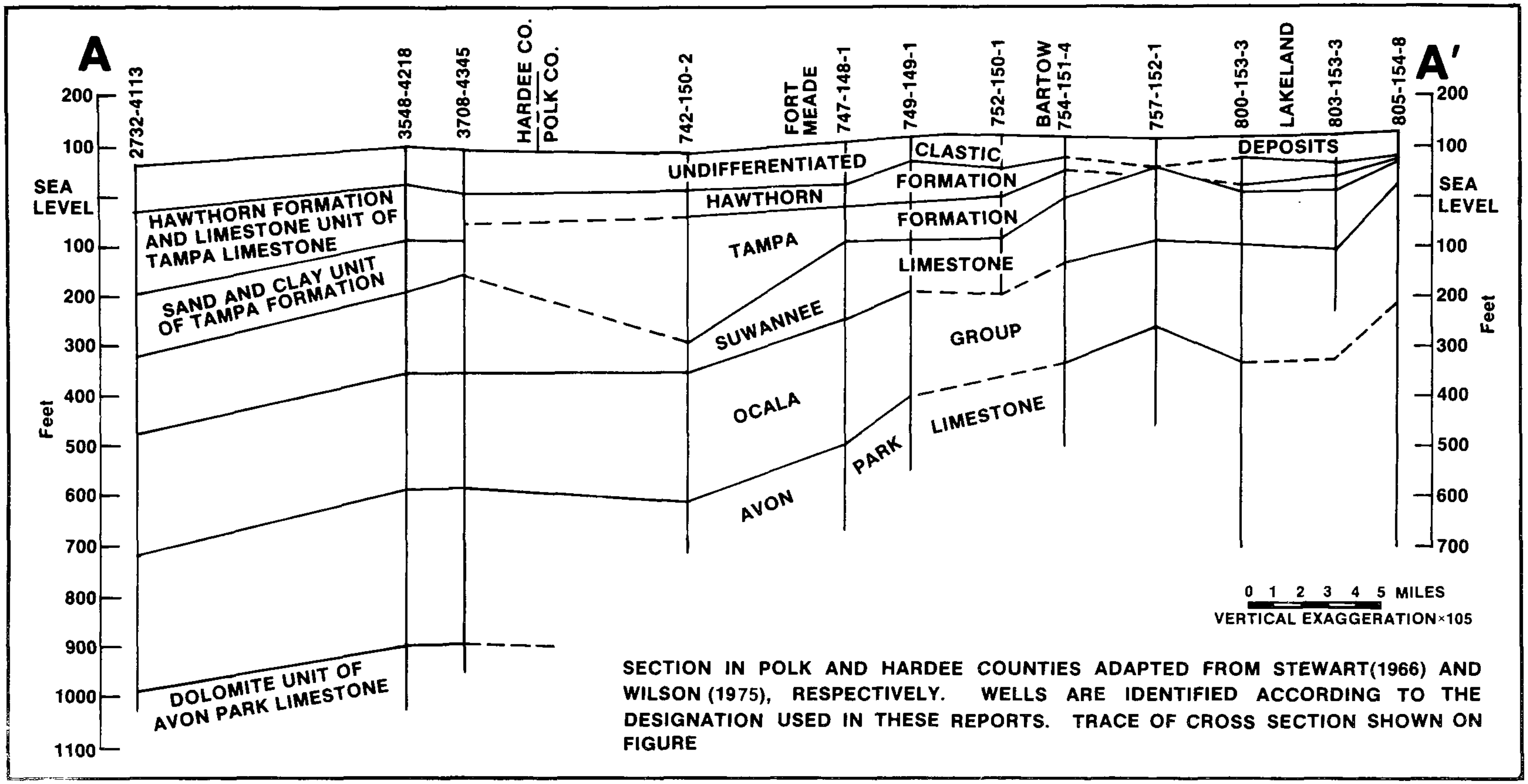
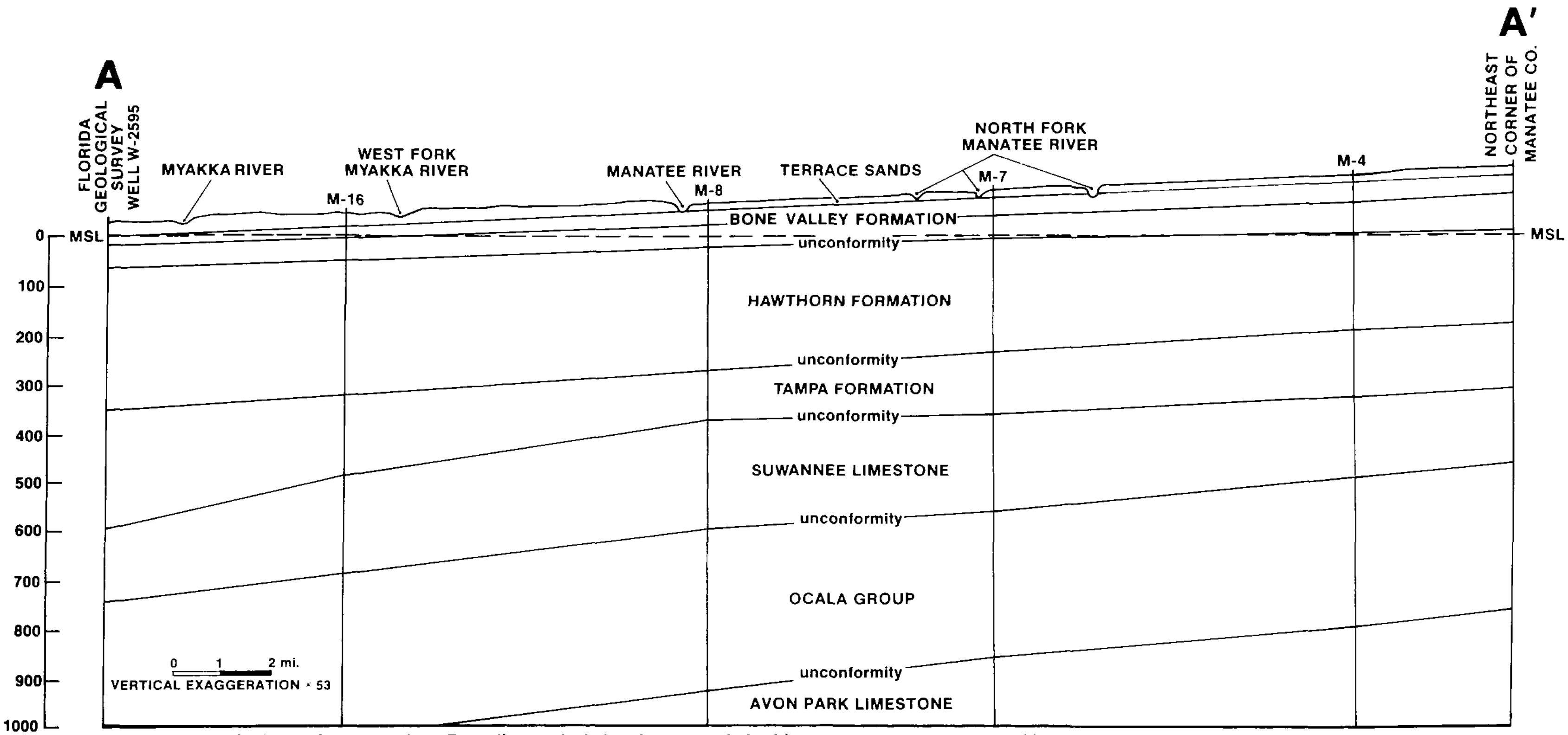


Figure 2. Generalized geologic cross section through southern Polk and northern Hardee Counties.



See Figure 7. for trace of cross section. Formation contact elevations were derived from structure contour maps, thickness data, and well logs presented by Peek(1958). Wells M-12, M-8 etc.are shown for orientation purposes only as these are shallow wells.

Figure 3. Generalized geologic cross section through northeastern Manatee County.

Formation (Cathcart, 1963a) which is generally present south of the Alafia River and west of the Highlands Ridge. It is present in Polk, Hillsborough, Hardee, DeSoto, Charlotte, Manatee, and Sarasota Counties (Cathcart and McGreevy, 1959; Stewart, 1966; Wilson, 1975). A source for part of the Bone Valley, the Hawthorn has an irregular upper surface and is sometimes sufficiently enriched in phosphate to constitute part of the matrix (Hoppe, 1976). In Manatee County the Hawthorn contains more clastic materials and is thicker relative to the section in Polk County (Cathcart, 1963a). From east to west, it becomes increasingly silty as well. At the Swift Chemical Company phosphate mine area in northeastern Manatee County, the Hawthorn is predominantly silt whereas in Hardee County it is characterized by clay.

Southward in Manatee County and particularly in the area of the Manatee-Sarasota County line, the Hawthorn is exposed or quite shallow, rather clayey, and the principal source of phosphate ore. Phosphate deposits, presumably from the Hawthorn, are exposed in the banks of the Intercoastal Waterway Canal in the area of Casey Paso. Much of Sarasota County is underlain by phosphatic sediment beneath twenty feet or less overburden which thins or is absent to the west.

The Tampa Formation which underlies the Hawthorn Formation was originally identified (Parker et al., 1955) from subsurface data in the Tampa area where the unit is predominantly limestone and a prominent aquifer in the Floridan aquifer system. Elsewhere in central Florida and particularly in southern Polk County and adjacent portions of Hillsborough, Manatee and Hardee Counties, clastic materials are common in the lower part of the Tampa which acts as a confining layer. Use of the term "Tampa Formation" was recommended by Parker (Geraghty and Miller, Inc., personal communication, February 25, 1977) and is so used herein.

The lithological sequence of the Tampa Formation and its role in the Floridan Aquifer system in central Florida has been debated for many years. It is generally considered a limestone in which there occurs a confining clayey member. Stewart (1966) contended that the clay unit is at the top of the Tampa. However, Wilson's (1975) study of Hardee and DeSoto Counties revealed a persistent and extensive clay and silt unit at the bottom of the Tampa Formation. This is generally believed to be true in southern and southwestern Polk County as well, where the Tampa Formation is present only as a clayey unit (B. Boatwright, Southwest Florida Water Management District, personal communication, February 16, 1977). It is absent in northern Polk County (Pride et al., 1966). In Manatee County and the western third of Hardee County it is largely made up of carbonates (Wilson, 1975) at least in part equivalent to the clay and silt member present in Polk and Hardee Counties. In Manatee County the clay and silt member is believed present only in the northeast corner (based on extension of the trends reported in Hardee County by Wilson, 1975). The Tampa Formation generally dips south or southeast in Polk County (Stewart, 1966) and to the southwest in Manatee County (Peek, 1958).

AQUIFER SYSTEMS AND GROUND-WATER FLOW

For the purpose of this report three principal aquifers are defined in the study area: The Upper and Lower Floridan aquifers which are typically confined and an unconfined local shallow aquifer. These are schematically shown in Figure 4 which also depicts the principal geologic units present. The degree of interconnection between aquifers is highly variable with location and, in effect, creates the large Floridan aquifer system which is made up of a series of aquifers and confining layers. The most prolific aquifer is the Avon Park Limestone. The initial discussion which follows is applicable primarily to Polk County and immediately adjacent portions of Hillsborough, Manatee, and Hardee Counties.

Unconfined or water table conditions occur in the unconsolidated surficial sediments and locally may extend to the lower part of the Hawthorn Formation. The Floridan aquifer system, composed of at least five major stratigraphic units and individual aquifers, includes the Upper and Lower Floridan aquifers as defined herein. In most of the study area the Lower Hawthorn and the Upper Tampa belong to the Upper Floridan aquifer which is sporadically distributed and variable with respect to head, yield characteristics and water quality. In northeastern Manatee County at the Swift Chemical Company mine site and at

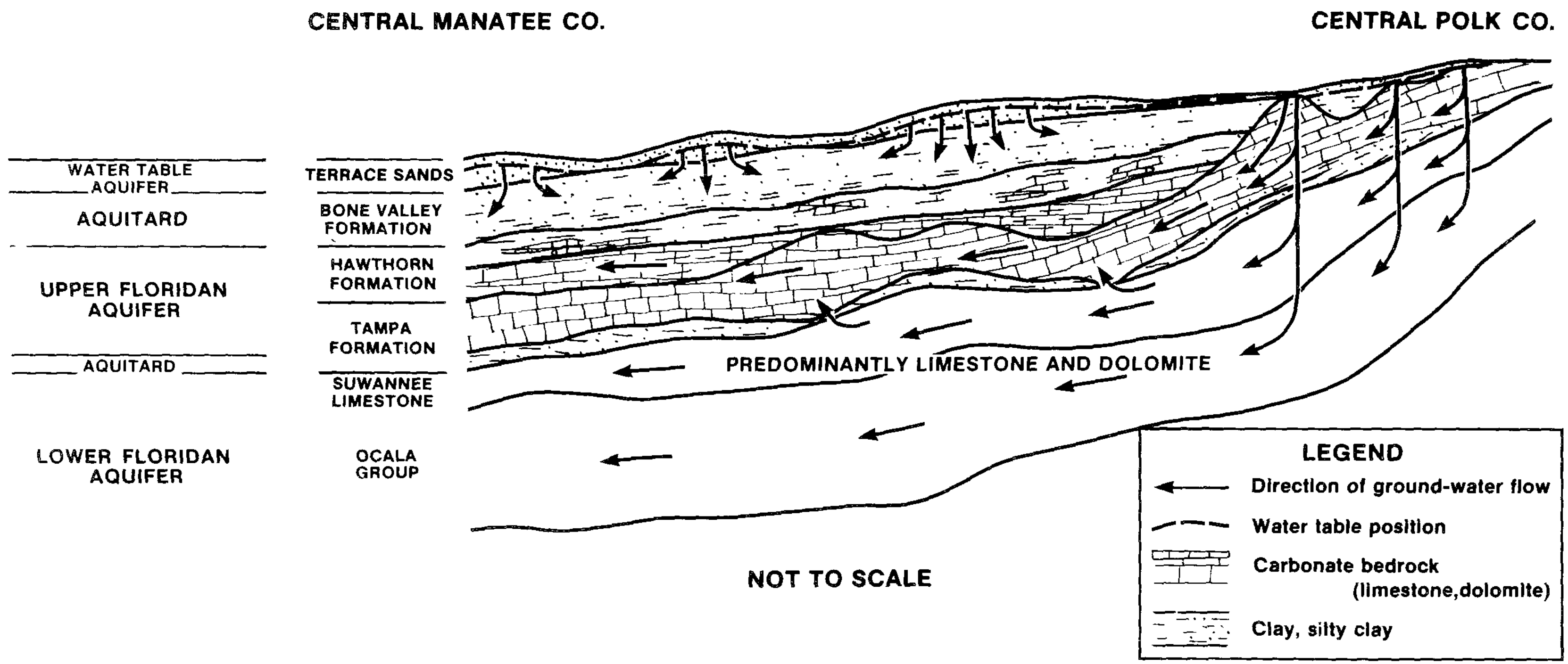


Figure 4. Generalized southwest-northeast hydrogeologic cross section through Polk and Manatee Counties.

the Phillips site in Desota County, a distinct Upper Floridan aquifer is not present (B. Boatwright, Southwest Florida Water Management District, written communication, June 6, 1977). Successively deeper carbonate units below the Tampa are part of the Lower Floridan aquifer which extends throughout most of central Florida. The Lower Floridan is typically under artesian pressure and water encountered in a bore hole penetrating a given aquifer will rise above the elevation of the stratigraphic boundary between the aquifer and overlying units. In certain instances the rise is sufficient to allow water to flow to the land surface but this condition now exists in only a few areas. Because of heavy pumping, particularly in southwestern Polk County and Southwestern Hardee County, water levels or head in the Lower Floridan are falling. Under completely natural conditions they were generally also below those in shallower aquifers except in areas where there were or are flowing wells developed in the Lower Floridan. Pumping, therefore, is causing increased downward flow in much of the study area.

The foregoing explanation is highly simplified and is probably applicable only to that portion of the study area in Polk County and immediately adjacent portions of Hillsborough, Manatee, and DeSoto Counties. Aquifer boundary conditions are largely stratigraphic and therefore variable depending on the persistence of lateral and vertical successions and structural controls. For example, stratigraphic relationships of the surficial sand unit and the lithologic makeup of the Hawthorn are very influential in determining the amount of recharge to the latter and whether it constitutes an aquifer or a semi-confining unit. Similarly, development of solution channels and other karst features in the Hawthorn and Upper Tampa Formations determine in part the amount of recharge from local precipitation or other hydrologic events at the land surface. Where the Hawthorn is thick and areally extensive, karst is not well developed. For Sarasota and Manatee Counties, separation of the Upper and Lower Floridan aquifers is generally not possible. In large part this is due to scarcity of stratigraphic and hydraulic information and because the limited facies data available (Wilson, 1975) indicate different conditions than the area to the northeast.

Structural elements in Polk and Manatee Counties are not topographically prominent but may play important roles in ground-water occurrence and movement in the Floridan aquifer system. The principal structural element in central Florida is the north-trending Peninsular Arch which is east of Polk County. Along the west flank of the arch is the Ocala Uplift, the south end of which extends into northern Polk County (Figures 8 and 9, in Pride et al., 1966). The Ocala Uplift imposes both hydrologic and geologic control on ground water in central Florida. The elevated position of the arch over geologic time allowed erosion and/or non-deposition, thereby positioning more permeable carbonate units at or near the land surface. This facilitates increased recharge. In addition to the stratigraphic framework, lateral and vertical controls on flow include paleokarst and fault planes associated with uplift, deposition/erosion cycles, and paleo-weathering features. Flanking the highland area at depth are less permeable materials which act as semi-confining units and aid in the creation of artesian conditions. The combination of increased recharge, elevated topographic position, stratigraphic boundary conditions, and regional dips generally to the south, southeast, or southwest gives rise to artesian conditions in the Floridan aquifer, and to a more local extent, in the basal limestone of the Hawthorn Formation. Most of the foregoing features are schematically shown in Figure 4.

INFLUENCE OF MINING AND PROCESSING

Strip mining and chemical processing as practiced in Florida's central phosphate district can affect ground-water as a result of activities associated with three broad categories: 1) pre-mining site preparation, 2) waste disposal related to ore extraction/beneficiation/chemical processing, and 3) post-mining site reclamation and slime pond or gypsum pond maintenance. Figure 5 shows the major operations involved in mining. By convention within the industry, the term mining includes beneficiation. Overburden consisting of surficial sand and the Bone Valley unit is stripped with draglines to expose the matrix. Water pumped from the pits or recycled from the slime ponds, supplemented with water from the Floridan aquifer, is used to convert the matrix to a slurry which is pumped to the beneficiation plant. There, screens and flotations separate the phosphate from the sand and slime tailings which are piped to disposal ponds. Makeup water is obtained primarily from deep wells and from water added to the system as precipitation, ground-water inflow, or matrix moisture. Mining may go as deep as the carbonate unit

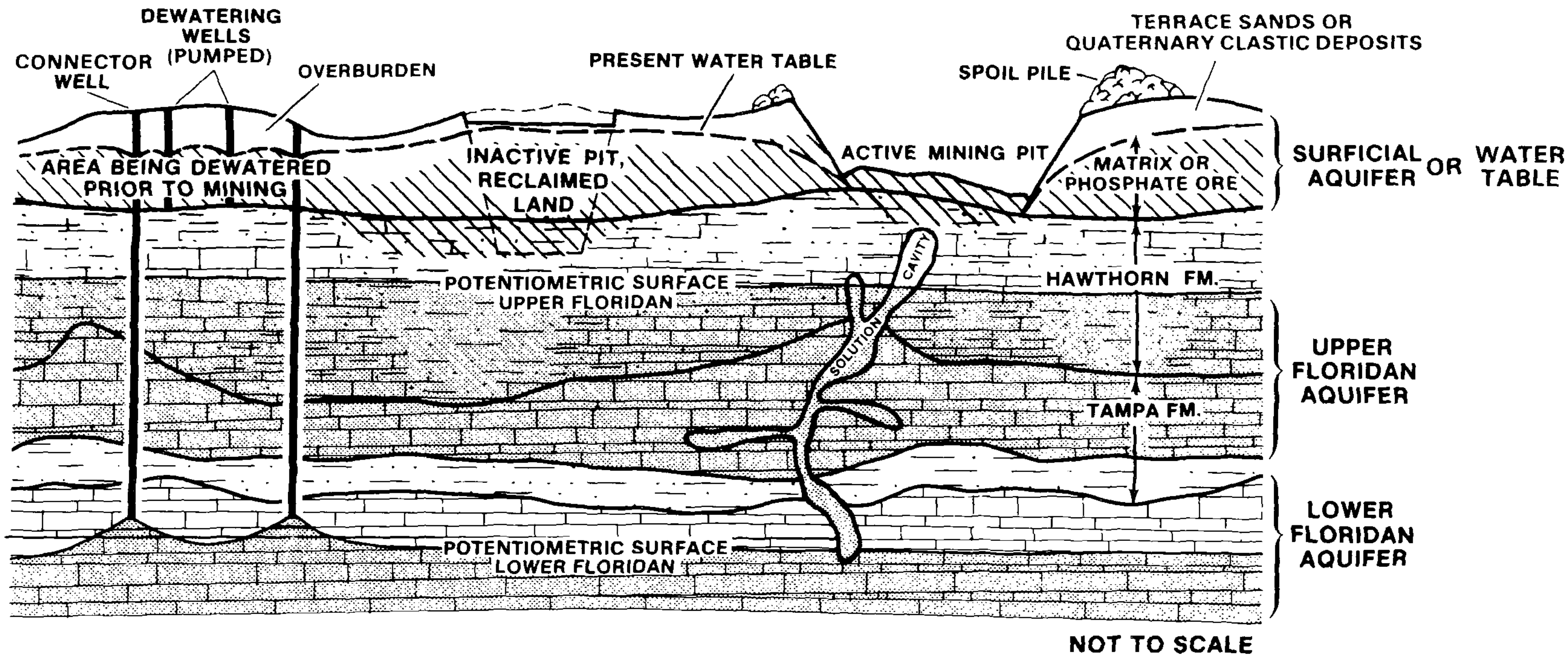


Figure 5. Interaction of mining operations and the hydrogeologic system.

of the Hawthorn Formation. After stripping the ore, overburden is replaced and shallow ground-water levels, drawn down to allow mining, gradually recover

The stratigraphic units affected by excavation are shown in Figure 5. Also shown are the water table and Upper Floridan aquifers, wells used for water supply and dewatering, and water table position. Due to nonuniform limestone distribution in the Hawthorn Formation and differences in the vertical extent of phosphatic matrix, many or even most mines are not likely to extend to the uppermost beds of the Floridan aquifer. In certain areas of active mining, particularly in Polk County, shallow confining materials may be removed and increased recharge to the Floridan aquifer may occur. Another suspected but poorly documented source of recharge results from occasional sinkhole collapse beneath slime or gypsum ponds. In the case of the latter, dissolution of carbonate strata in contact with acidic gypsum pond water may be a factor. Only one case of such a collapse is known and a few others are suspect. Cavities are not always present and collapse incidence is believed to be low. Remote sensing data indicate that seepage through sand tailings dams containing gypsum ponds is common (Coker, 1971; 1972).

Use of connector wells is typified by the International Minerals and Chemical Corporation (IMC) installation at the Kingsford mine of more than 50 such wells completed in the surface aquifer and in the underlying Floridan aquifer (Hoppe, 1976). Cathcart (USGS, personal communication, February 8, 1977) indicates this practice has become widely used as it is an effective method to dewater the ore zone and sand cover prior to mining. Dewatering is not always necessary depending on the depth to water relative to the base of the ore body and the type of mining operation. Because of declining heads in the Lower Floridan aquifer, recharge via connector wells is beneficial with respect to the water supply picture. Credit is given for the amount of water recharged, thereby allowing more pumping from the Lower Floridan than if only natural recharge occurred. The IMC recharge program also includes 60 observation wells and 20 surface monitoring stations to preclude introduction of low quality waters to the Floridan aquifer (Hoppe, 1976). As head in the Floridan aquifer decreases in areas of heavy pumping, head differential relative to shallow aquifers will increase and recharge wells will become increasingly popular. In the past more use was made of pumped wells or pits to effect dewatering. Water was discharged into adjacent pits or discharged to surface water courses. The latter practice is not favored because water is exported from the basin rather than being used to replenish ground-water resources, particularly the Floridan aquifer system.

Stripping of the overburden and leach zone and subsequent removal of the phosphate ore or matrix with draglines thoroughly disrupts the natural sequence of overburden, leach zone and matrix. Although a leach zone is not always present it is significant from a radiation standpoint because it is believed to contain the greatest concentration of uranium (Golden, 1968). Formerly, overburden and leach zone materials were dumped on vacant ground adjacent to the trench to allow removal of the matrix. As successive parallel trenches are cut, the overburden and leach zone materials are put into adjacent, mined-out cuts. In recent years, overburden and leach zone materials are separated so that overburden is replaced last. Ore is hydraulically disaggregated in an open pit and pumped to a washer plant as slurry containing about 40 percent solids. For a typical mine, about 400 acres/year will be stripped, resulting in the use of 4.5 billion gallons of water for slurry makeup.

Water utilization, primarily from the Floridan aquifer, has caused significant decline in the potentiometric surface of the Floridan aquifer between 1964 and the present. In central Florida approximately sixty percent of the water pumped from the Lower Floridan aquifer is for irrigation and about twenty percent for the phosphate industry. Municipal use accounts for the balance. Introduction of new techniques for beneficiation have reduced the phosphate water usage and at least one company, Brewster Phosphates, Inc., is operating without need for water withdrawal from the Lower Floridan aquifer.

The recent configuration of the potentiometric surface in the Floridan aquifer is represented in maps prepared by the U.S. Geological Survey and the Southwest Florida Water Management District (Stewart et al., 1971; Mills and Laughlin, 1976). Significant potentiometric troughs are centered in the area due north of Bartow, as well as in north-central Manatee County and northwestern Sarasota County. The latter two troughs developed in the period

1969-1975 and are probably related to irrigated agriculture as the phosphate industry does not operate in these areas.

Over much of the central Florida study area, the vertical flow gradient has been downward although there are areas along the coast and along the Peace River where gradients are or were upward. With heavy pumping and steepened downward flow gradients there is increased potential for downward movement of shallow ground water. Increasingly active monitoring of shallow and deep ground water is now required by the Southwest Florida Water Management District and as a part of the development orders appurtenant to the DRI process.

Drainage water associated with mines is not usually discharged to surface streams. Although mine water and ambient ground water are intimately associated, the 1973 USEPA study revealed that recirculated water (tail water from slime ponds) and pit seepage at two mines in Florida contained only 0.28 to 1.5 pCi/l dissolved radium-226. In comparison, leachate from gypsum spoil piles at chemical processing plants contains 60 to 100 pCi/l. It would appear that potential adverse effects on ground-water quality would primarily be a result of chemical processing (to produce phophoric acid) and accompanying waste handling featuring gypsum ponds and piled gypsum waste.

Ore beneficiation utilizes recycled slime pond water supplemented with deep ground water. Tailings and slime are emplaced in specially constructed settling basins and mined out pits. Although the ratio varies depending on ore grade, a general guide is that a ton each of sand tailings and slime is generated per ton of phosphate rock product. One of the critical problems the phosphate industry faces is dewatering large amounts of clay slime which now requires substantial funds for dam construction, maintenance, and monitoring because solids remain in suspension and/or will not dewater. As a result the slime ponds not only commit a large amount of otherwise usable water and land, but also are potential sources of radiochemical and other pollutants that can affect nearby water resources. Recent and ongoing studies funded by the U.S. Bureau of Mines, in particular, show that accelerated settlement of slimes is economically feasible. One of the more promising methods involves mixing sand and slime fractions to increase settling and water expulsion.

As the number and/or capacity of chemical processing plants increases, attendant gypsum piles and acidic effluent may pose increasing problems with respect to long-term stabilization of wastes. Both the effluent and the gypsum are elevated in radium, necessitating long-term stabilization to prevent leachate formation and migration. No monitoring studies are available detailing ground-water quality around such piles or stabilization techniques for the pile proper. One pond near Mulberry failed by sinkhole collapse in 1975 and a study by Zellars and Williams (1977) showed average leakage of 13 percent or 2039 gallons per minute for two years of record at two mines and one year at a third. The amount of leakage from gypsum ponds is unknown.

SOURCE TERM CHARACTERIZATION

"Phosphate rock" is a commercial term denoting a rock with one or more phosphate minerals and of sufficient enrichment and composition to be usable as is or after concentration. In Florida, the principal ore is phosphatized limestone.

The principal phosphorus-bearing minerals in the central Florida phosphate deposits are in the carbonate apatite group with the general formula: $Ca_5\ (PO_4)_3(F,Cl,OH)$. Phosphate exchanges with small quantities of VO_4, AsO_4, and SO_4 whereas Na, Si, Th, U, and rare earths can exchange with Ca. Such replacement plus the cryptocrystalline structure gives rise to the term collophane, indicative of a nondefinitive suite of carbonate apatite minerals which are the essential minerals of phosphorite (sedimentary phosphate rock). Uranium, vanadium, selenium, chromium, and rare earths can be present in sufficient concentrations to constitute actual or potential by-products.

Natural uranium, present in Florida phosphate deposits in concentrations of 0.1 to 0.4 pounds per ton (Stowasser, 1976), consists of approximately 99.3 percent (by mass) uranium-238. Radioactive decay of uranium-238, commonly known as the uranium series, gives rise to uranium-234, thorium-230, radium-226, and radon-222, amongst others. For reasons of half life, toxicity and mobility not all members of the decay series, which ends with the formation of (stable) lead-206, present equal hazard. Although all radiation exposure is considered harmful and adverse effects are assumed proportional to dose (linear, no threshold hypothesis). Radium-226 is singled out because of its known occurrence in areas of phosphate mineralization. It is long lived (1600 years), has relatively high transfer from the gastrointestinal tract to the blood, and has an affinity for bone where it replaces calcium and is toxic due to high energy alpha decay characteristics. Study is also facilitated by the data base from sampling efforts in the last decade and particularly from 1973-1976. Uranium and principal progeny are in secular equilibrium in the matrix

(Guimond and Windham, 1975) and presumably in the leach zone as well. Elevated levels of radon in structures built on reclaimed land (U.S. Environmental Protection Agency, 1975; and 1976b; Fitzgerald et al., 1976) suggest that uranium and radium distribution in shallow depths may be increased relative to pre-mining levels. Presumably this occurs if leach zone materials are mixed with other overburden materials as part of overall reclamation. What effect weathering and leaching from rainfall may have on redistributing radioactivity in the subsurface has not been determined and is of legitimate concern, particularly with respect to long term water quality in the water table aquifer.

Before discussing various liquid and solid wastes associated with phosphate mining and processing, some description of basic operations may be useful. After the overburden is stripped, ore is excavated by draglines, put into slurry form with hydraulic jets, and pumped to nearby washing plants for size separation. Minus-200 mesh particles or slimes are discharged to slime ponds for settling to allow reuse of water. Slimes amount to about one-third of the original ore volume and represent about one-third of the total mineral values extracted. In addition they are costly to handle and store. Slime production from Florida alone is estimated at 36.3 million short tons in 1973 (Guimond and Windham, 1975). Estimated radium content is 1480 Curies. Slimes are potentially damaging to water resources as a result of entrance to ground water reservoirs or dike failure and release to streams. Reported radium-226 in Florida slimes is 45 pCi/g versus 42 pCi/g in phosphate products (Guimond and Windham, 1975).

After separation from the ore, sand tailings are 1) piped to sand piles as a slurry, 2) used to build up dikes around slime ponds, and 3) placed in mined out areas. Because sand tailings yield water readily, there is increased interest in using them to assist in slime stabilization or to bury them in mined out areas where their permeability can be used to store and transmit ground water for use in ore transport and beneficiation. Amine flotation water used for sand separation is discharged to mine pits and recycled. Radium content of sand tailings is rather low, averaging 7.5 pCi/g. Radioactivity primarily is associated with the phosphate fraction, one-third of which is slime waste and two-thirds product. Approximately 380 Curies of radium-226 in 55.8 million short tons of tailings were generated in Florida alone in 1973 (Guimond and Windham, 1975).

Phosphate rock separated from the ore is either exported or sent to a chemical processing plant for conversion to superphosphate by treating finely ground phosphate rock with sulfuric acid:

$$\underset{\text{tricalcium phosphate}}{Ca_3(PO_4)_2} + 2\ \underset{\text{sulfuric acid}}{H_2SO_4} + 6\ H_2O = \underset{\text{monocalcium phosphate}}{CaH_4\ (PO_4)_2} + 2\ H_2O + 2\ \underset{\text{gypsum}}{(CaSO_4 \cdot 2H_2O)}$$

The product of the above reaction is superphosphate. Monocalcium phosphate is soluble in water and therefore plant available. Gypsum remains in the product and dilutes it. Phosphoric acid is produced by adding additional sulfuric acid and separating phosphoric acid from the gypsum according to the reaction:

$$Ca_{10}F_2(PO_4)_6 + 10\ H_2SO_4 + 20\ H_2O = 10\ CaSO_4 \cdot 2H_2O + 2\ HF + 6\ H_3PO_4$$

Phosphoric acid can be reacted with additional phosphate rock to yield triple superphosphate which contains 45 to 48 percent P_2O_5. In the above reaction, large piles of gypsum and ponds of acidic effluents result. Production of other fertilizers such as diammonium phosphate, urea-ammonium phosphate, or "complete" fertilizers consisting of phosphorus, nitrogen, and potassium compounds is increasing due to market demand and favorable transportation economics.

Radionuclide concentrations in product, slime, and sand tailings materials from Florida phosphate deposits were determined in previous USEPA studies (1973; and Guimond and Windham, 1975). These, in turn, were expansions of the work begun by Spalding (1972) of the Texas A & M Oceanography Department. Data presented by Guimond and Windham (1975) show that beneficiation processes do not alter the isotopic ratios, which are essentially in secular equilibrium for the uranium, actinium, and thorium decay series. However, redistribution of radionuclide concentrations occurs among the three principal fractions cited. Uranium occurs as a trace element in the phosphate-bearing minerals, hence it tends to remain with the fertilizer, whereas most of the radium is concentrated in the solid and liquid wastes. Phosphoric acid is enriched in radium-226, uranium, and thorium relative to the concentration of phosphate deposits. The sand tailings fraction contains about 12 percent of the total radioactivity, whereas the slime and product fractions contain 48 percent to 40 percent, respectively. Overall, about 60 percent of the activity, which in 1973 amounted to over a thousand Curies each of radium-226, uranium-234 and -238, and thorium-230, is contained in the slime and sand tailings (Guimond and Windham, 1975, Table 2).

Radium concentrations are greatest in gypsum wastes associated with phosphoric acid plants (U.S. Environmental Protection Agency, 1973; Guimond and Windham, 1975). Whereas seepage into mine pits and recirculated mine water contained 0.28 to 1.5 pCi/l dissolved radium-226, gypsum water at four separate fertilizer plants ranged from about 50 pCi/l for plants without recycling and 90 to 100 pCi/l in those that did (U.S. Environmental Protection Agency, 1973). By-product gypsum from central Florida acid plants contains 21 to 33 pCi/g radium-226 compared to 45 pCi/g in washer plant slimes and 42 pCi/g in phosphate rock product. Gypsum solubility and high rainfall (50 inches per year) indicate continuing measures will be necessary to control leachate production and migration from such piles. It is recommended that techniques developed for moisture control in common sanitary landfills and for land disposal of toxic wastes, including uranium mill tailings, be investigated for their applicability to gypsum piles. Additional measures are necessary for treatment and immobilization of the liquid fractions.

Dissolved radium-226 in slime pond influents and discharges consistently averages less than 5 pCi/l and typically less than 2 pCi/l (U.S. Environmental Protection Agency, 1973; Guimond and Windham, 1975). Radium in the suspended fraction of the influents is more variable, ranging from 9.8 to 72.6 pCi/g (mean 33.5) on a weight basis and 10.2 to 2248 pCi/l (mean 673) on a volumetric basis. The latter is highly dependent on the amount of suspended solids in the slime discharge. In effect, radium content on a per unit weight (of undissolved solids) basis varies by a factor of seven, whereas the quantity of undissolved solids varies by a factor of 220. Total radium that potentially could contaminate ground water is therefore quite variable and suspended solids content is the more significant contributor. Analysis for "dissolved" versus "undissolved" radium is highly dependent on the pre-analysis methods. Acidification followed by filtration, wet chemistry, and counting will give a higher content of dissolved radium and a lower content of undissolved radium relative to methods calling for filtration first. More importantly, the amount of suspended and settleable solids in a given sample can greatly affect the analytical results. Thus it is apparent that ground-water monitoring for suspected or actual contamination in the vicinity of a gypsum pond or slime pond, or monitoring of ground water from mineralized stratigraphic intervals calls for different procedures than in the case of a public health related survey involving water supply wells. This point will be developed further in a subsequent section.

On the basis of available grab sampling data, radium solubility does not appear to increase as a result of residence time or other conditions in slime ponds. Dissolved radium in discharges ranged from 0.02 to 2.2 pCi/l and total radium (dissolved + undissolved, pCi/l) never exceeded 3.0 pCi/l at any one facility. Seepage to ground water, however, may contain higher total radium depending on the transport route (conduit versus intergranular seepage) and the suspended solids content of the wastewater.

In summary, seepage, overflows, and accidental releases from the various basins and pits put the wastes in actual or potential contact with adjacent water resources. Although one can only speculate on the basis of very limited available data, mining practices probably introduce marked changes in the chemical and hydrologic stability characterizing the ore body and associated overburden and leach zone. The effects, if any, on increased leaching of radionuclide-bearing minerals are unknown. From a ground-water protection standpoint, intergranular seepage from slime ponds would not be expected to grossly change radium concentrations in native ground water, particularly in the unconfined aquifer. However, movement of slimes high in suspended solids into solution cavities and other secondary permeability features could result in contamination. Sampling of such contamination using methods whereby acidification is followed by filtration will give anomalously high results for dissolved radium. Measurement of the suspended solids content and radiochemical character thereof as well as dissolved radium should be incorporated in monitoring studies of slime pond seepage to ascertain the degree of natural filtering and the prevalence of turbid seepage, if any. Wells completed in the upper limestone unit and situated at or very near pond perimeters are recommended.

Field and laboratory studies by Guimond and Windham (1975) of phosphoric acid plant waste treatment using basic solutions containing quick lime, hydrated lime, limestone, or dolomite indicate the feasibility of removing at least 94 percent of soluble radium-226. Use of the double liming procedure to markedly reduce dissolved radium was also recommended in a previous USEPA (1973) study. Coprecipitation of radium in calcium-radium sulfate appears to be the removal mechanism which is facilitated by abundance of calcium, sulfate and phosphate ions, reduced solubility of radium sulfate at neutral or near-neutral pH, and settling of precipitates. In this way, process water containing 60 to 90 pCi/l of dissolved radium can be treated so as to reduce concentrations to between 1 and 3 pCi/l. Neutralization of acidic effluents would greatly reduce soluble radium content. Whether such effluents actually dissolve carbonate strata beneath gypsum ponds and thereby increase incidence of solution cavity collapse/development is unknown. If additional study confirms such dissolution, there is additional reason for treating the wastes.

SOURCES OF RADIOCHEMICAL DATA

Analytical data for radium-226 in water were primarily obtained from the following sources: 1) U.S. Environmental Protection Agency, 2) Federal Water Pollution Control Administration and 3) U.S. Geological Survey These data are tabulated in Appendices 1, 2, and 4. Radium and gross alpha data were also obtained from the Southwest Florida Water Management District and from preciously published reports on radium in Florida and the United States. Table 2 summarizes the data sources, number of analyses, time of collection, and how the data are used in this report. Only an approximate tally of analyses actually used is possible. For example, the 1966 survey by FWPCA produced data for 105 sampling points, all of which are listed in Appendix 2. Only about 40 of these had sufficient well information or were properly located

TABLE 2. SUMMARY OF PRINCIPAL SOURCES OF RADIUM-226 DATA[1]

SOURCE	TIME OF COLLECTION	UTILIZATION IN PRESENT STUDY	NUMBER OF OBSERVATIONS	PREANALYSIS TREATMENT[2]	LOCATION OF DATA IN REPORT	AREA COVERED
USEPA	1973-1975	Analyze spatial variation	71	A/F	Appendix 1	Primary study area[3]
USGS - Irwin and Hutchinson, 1976	1974-1976 1974-1976	Analyze spatial variation	64 5	U/F A/F	Appendix 1	Primary study area
	1954-1957		500	U/F	Not tabulated	United States
USGS - Scott and Barker, 1962	1954-1957	Analyze spatial variation	86	U/F	Not tabulated	Atlantic and Gulf Coast Plain
	1954-1957		35	U/F	Figure 9	Florida, excluding study areas, (see Figure 8)
USEPA (for Sarasota County Health Department)	1975-1976	Analyze spatial variation	49	A/F	Appendix 4	Supplementary study area in Sarasota County
FWPCA - Shearer et al., 1966	1966	Analyze spatial variation	105	U/F	Appendix 3	Primary study area

1. Radium-226 dissolved in water
2. U = unpreserved, A = acidified, F = filtered
3. Desoto, Hillsborough, Hardee, Manatee and Polk Counties (shown in Figure 1)

relative to the study area to allow use in the statistical analysis. In other instances, gross alpha or stable chemical data from previous studies were utilized. These are not included in Table 2.

The FWPCA data were originally developed by Shearer et al. (1966) as part of a 1966 survey by the Technical Advisory and Investigations Branch, Cincinnati, Ohio. Radium-226, radon-222, natural uranium, thorium-230, polonium-210, gross alpha, and gross beta were determined together with gross chemical analyses on 105 public and private water supply wells in central Florida. EPA data (category 1 above) were collected from 1973 to 1976 by the Office of Radiation Programs, in cooperation with county and state health departments, and analyzed by the Office of Radiation Programs, Eastern Environmental Radiation Facility, Montgomery, Alabama. Also included in Appendix 1 are selected USGS data from a 1974 to 1976 survey by Irwin and Hutchinson (1976). Open file U.S. Geological Survey data from Florida were collected in the course of a nationwide assessment of radium in ground water by Scott and Barker (1962). These data were provided by R. Scott (private consultant, Atascadero, California).

The locations of wells sampled by the USEPA, the USGS, and FWPCA in Polk, Hillsborough, Hardee, Manatee, and Sarasota Counties are shown in Figures 6, 7, and 13.

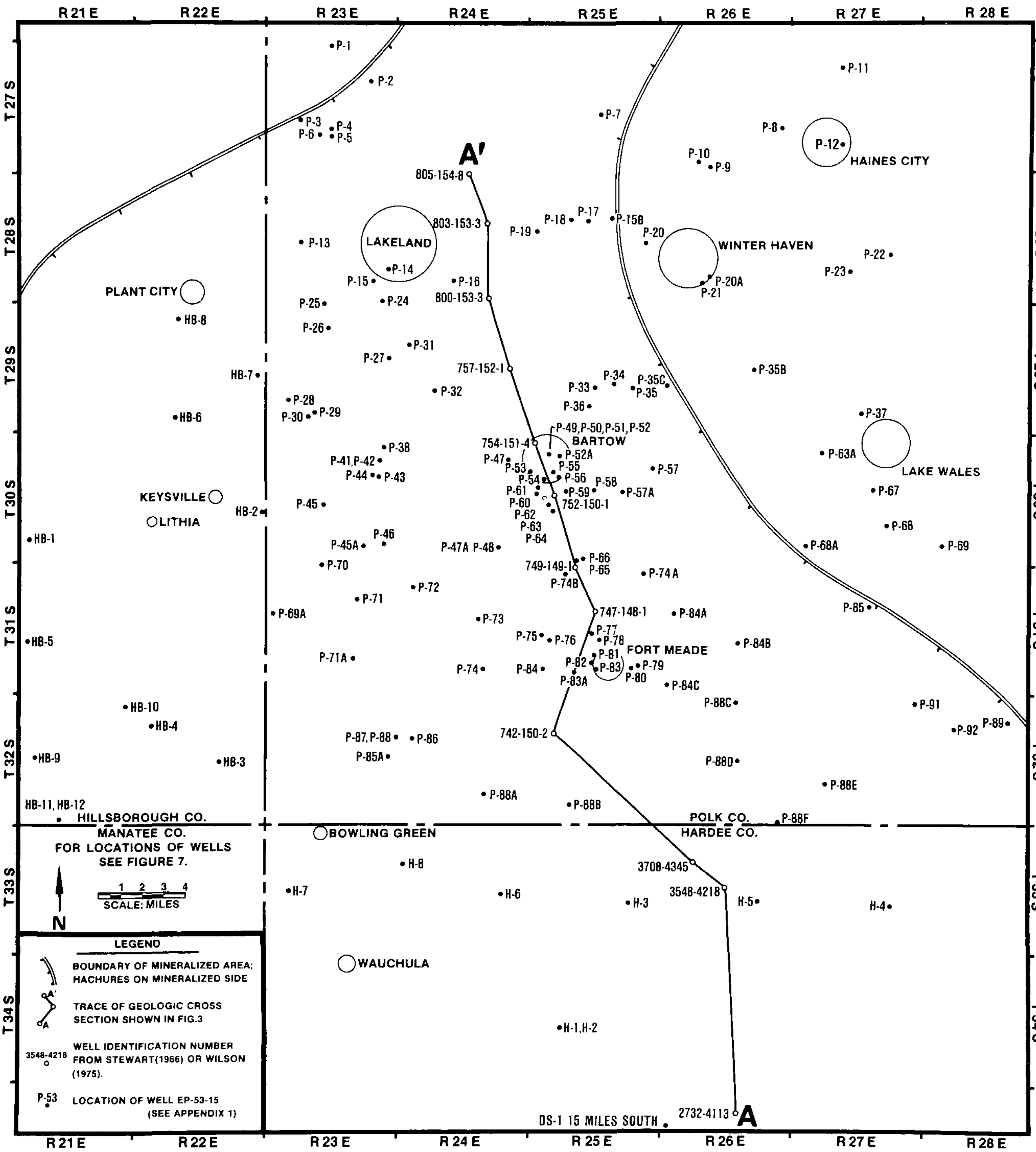


Figure 6. Location of wells sampled in Polk, Hillsborough, and Hardee Counties.

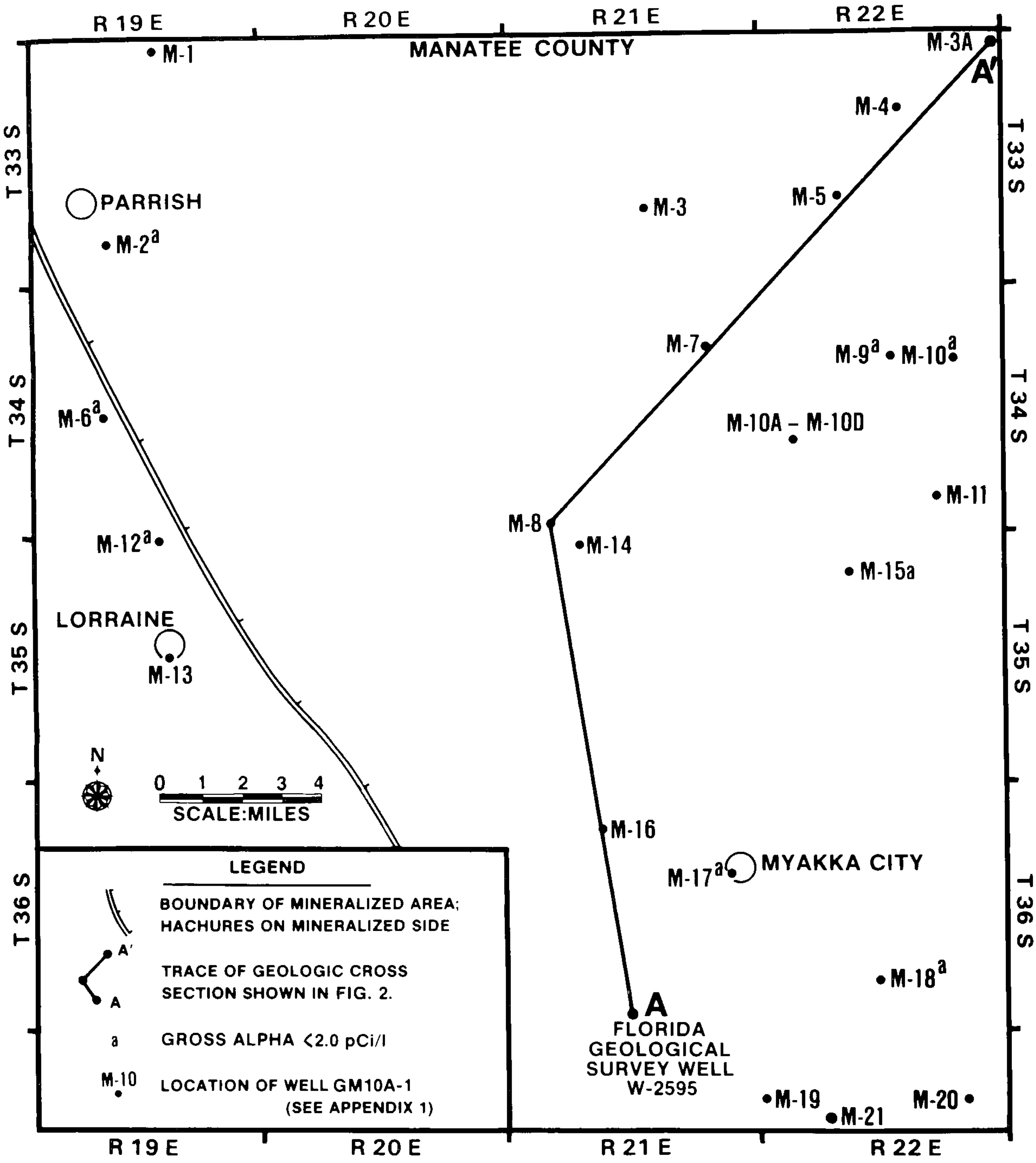


Figure 7. Location of wells sampled in Manatee County.

TECHNIQUES FOR MONITORING RADIUM-226 IN GROUND WATER

MONITORING OBJECTIVES

Two commonly recognized objectives for monitoring radium-226 in ground water include public health investigations, (i.e.,the radium content relative to established drinking water standards), and environmental quality studies to ascertain ambient quality or changes therein, typically as a result of human activities. Both objectives are quite necessary but unfortunately data collected for one purpose can be rather inadequate with respect to the other. Ideally, both needs should be served. Some of the findings and difficulties encountered using available data in the present study may help improve future investigations and for this reason are elaborated upon.

SAMPLING POINTS AND METHODS FOR SAMPLING RADIUM-226 IN GROUND WATER

By far most radium-226 analyses of ground water collected in Florida up to the present time are based on one-time grab samples collected at a well head or spring orifice, or they are raw or finished water samples from a water supply system, most of which are supplied by a number of wells pumping into a common reservoir. Both sampling objectives cited in the previous paragraph utilize these various sampling points. Obviously, health-related studies are essentially restricted to wells and springs used for potable supply whereas ground-water monitoring studies will include and may solely use wells installed or at least utilized for monitoring purposes. Ultimately, trends in potable status would also be of concern. Certain characteristics of these sampling points, sampling methods, or physical attributes of the water sample, per se, necessarily interrelate to the objectives of a given study and the potential for reaching definitive conclusion.

Samples collected from public or domestic water supply wells in the study area are, with rare exception, equipped with pumps and the wells are actively used. Suspended solids are typically quite low and the water samples are likely to be representative of the aquifer(s) tapped. Because such wells are commonly completed with relatively large intervals or production zones, the water sample is a composite of quality in this interval. Wells used solely for monitoring, particularly shallow ones are generally not equipped with pumps and sampling is done with a bailer or thief sampler. If a pump is present, it is used intermittently for sampling purposes only. As a result, water quality in the borehole may not be representative of the aquifer(s) and suspended solids are likely to be higher than a well in daily use. Wells used solely for monitoring are used intermittently, typically are not equipped with pumps, and are completed with less care than supply wells. As a result they produce more settleable and suspended solids. Introduction of a bailer or thief sampler or startup of a pump in a dormant well can easily raise the level of suspended or settleable solids to concentrations not commonly found and certainly not acceptable in a potable supply well. Proper sampling of such wells and subsequent sample handling can markedly influence the analytical results and more importantly, the importance of the data relative to the study objectives.

SAMPLE PRESERVATION AND HANDLING

Water samples to be analyzed for radium-226 are usually either acidified and filtered before analysis or they are simply filtered. Marked differences in analytical results using the two methods commonly occur, due in large part to the amount and composition of settleable and suspended solids in the sample. Acidification immediately after sampling is favored in health-related surveys because it is reasoned that the water sampled is representative of the potable supply and that acidification to pH of about two duplicates conditions in the stomach. Another reason for acidification is to prevent sorption of radium onto the walls of the sampling container.

Samples collected for hydrologic investigations or as part of surveys to ascertain ambient and contaminated levels of radium in ground water are filtered as soon as possible after collection and preferably in the field. Dissolved radium is defined as that passing through the filter. Acidification to prevent plating out is optional. The USGS does not favor acidification for naturally occurring isotopes in the uranium and thorium decay series and believes that other factors such as Eh and oxidation state may be more significant, particularly for fission products (Thatcher et al., 1977). Dissolved radium may be markedly lower with this approach of filtering first and then acidifying as compared to acidification first, followed by mixing, digestion, and filtering. For example, in five of the six data pairs shown in Table 4, the USEPA data means range from 1.06 to 2.88 (mean 2.04) times higher than USGS data. The significance of this difference is weakened by the fact that the samples are not from the same wells. However, splits of three surface water and two ground-water samples collected by Irwin and Hutchinson (1976), were analyzed for radium-226 first using filtered raw water and then acidified raw water (followed by filtering) with the following results:

		Dissolved Radium-226, pCi/l		
Sample	Station	Untreated Samples (1)	Acidified Samples(2)	
1.	Lithia Springs near Lithia	0.68 ± .07	0.80 ± .08	
2.	Alafia River at Lithia	0.06 ± .012	0.53 ± .05	
3.	Peace River near Fort Meade	0.12 ± .024	0.58 ± .006	
4.	Well - Upper Floridan	0.24 ± .048	20.00 ± 1.4	
5.	Well - Lower Floridan	0.06 ± .012	0.14 ± .028	
	Mean for five samples	0.23	4.41	ratio = 0.052
	Mean for four samples	0.23	0.51	ratio = 0.45

Two sigma error terms shown include counting and analytical error; estimated as follows:
<.5 pCi/l : 20%; 0.5 to 2 pCi/l : 10%; 2 to 10 pCi/l : 7% (L. Schroder, USGS, personal communication, April 11, 1977). Ratio = untreated ÷ acidified.

They concluded that little difference was attributed to sample preparation but rather to the presence of particulate material which was thought to be high in Sample 4. From the comparisons presented by Irwin and Hutchinson, we conclude that dissolved radium-226 in acidified samples is 1.17 to 83 times higher than in untreated samples, and particulate material can greatly increase dissolved radium when acid preservative is used. The mean radium-226 content of the acidified USEPA samples is 2.85 pCi/l versus 1.84 pCi/l in filtered but unacidified samples in the Geological Survey data base (data contained in Appendix 1). If plating out occurs, samples with no appreciable suspended solids may show a lesser concentration of dissolved radium when the acidification step is omitted. However, this plating out hypothesis is not well supported in the literature. It is apparent then that analytical differences do exist as a function of sediment content and sample preservation. Although differences are unidirectional, they are rather variable and not subject to simple correction.

SIGNIFICANCE RELATIVE TO FUTURE STUDIES

The authors conclude that the available radium-226 data base for central Florida ground water is fragmented because of the different objectives and sampling/analytical methods incorporated in past studies. Future sampling efforts focused clearly on ascertaining public health significance of radium in ground water seem bound to utilize sampling methods involving acidification followed by filtration. Application of this method, in conjunction with sampling of monitoring wells using bailers, thief samplers, or very intermittent pumping is likely to generate spurious data for evaluating environmental levels of dissolved radium-226. Acidification of turbid water samples from public or private potable water systems is also likely to produce higher concentrations of dissolved radium than if the water is filtered before acidification. Techniques involving acidification in the field, followed by filtration in the laboratory, should be reserved for health-related surveys of water systems that are in use. In terms of settleable or suspended solids, samples must be representative of the water being consumed. Mere collection of samples, with little regard as to the amount and composition of suspended solids, combined with acidification prior to filtering, may produce analytical results with little technical value for public health or environmental monitoring purposes.

Monitoring studies to determine ambient conditions, temporal, or spatial trends, contaminant migration, or equilibria between dissolved and suspended fractions and between these and host strata with respect to radium require different sample handling procedures. Actual sampling points, be they wells or springs, can be either representative of a small vertical interval or volume of the subsurface or they can be points that are expressive of some average condition within an aquifer or an aquifer system. Depending on the objectives for a given study, one or both types of sampling points are of value. With respect to filtration and acidification, samples should be filtered in the field, if at all possible, or at least upon arrival at the laboratory. Filter papers should be saved for analysis of the activity in the solids. Acidification after filtering is recommended to prevent or reduce plating out.

Studies or at least data collection concerning radium in ground water of central Florida will continue. Misapplication of study objectives to the types of sampling points available, e.g., public health study objectives and sample handling applied to monitoring and connector wells, should be studiously avoided by regulatory agencies and industry alike. There is genuine need to study both environmental quality and public health in a multiple-aquifer, multiple land use setting. Cost effective and information-effective data collection programs are essential lest the next 30 years of mining activity and related monitoring simply mirror the past shortcomings.

RADIUM IN SURFACE AND GROUND WATER

Although it is beyond the scope of this report to give a detailed assessment of radium occurence in surface and ground water throughout the world and United States, a short discussion is included to put the observations in Florida and in the specific study area of this report into better perspective. It should be noted that some of the values refer to a composite of all radium isotopes whereas in the detailed part of this study only radium-226 is addressed. However, radium-226 is the most common isotope and is therefore believed to be a fair approximation of total radium. There are some important exceptions to this generalization and these will be noted in a later section. Table 3 is provided to summarize the text that follows.

CONCENTRATIONS IN CONTINENTAL AND OCEANIC WATERS

Radium concentrations in ocean and surface waters tend to be quite low. Koczy (1958) observed that near bottom water varied from 0.08 pCi/l in the Indian Ocean to 0.51 pCi/l in the Pacific Ocean, with surface ocean water at about 10^{-4} pCi/l. Tokarev and Shcherbakov (1956) considered 0.1 pCi/l as the mean for ocean water, compared to 0.1 pCi/l in fresh water lakes, and 0.2 pCi/l in rivers. Miyake et al. (1964) observed 0.08 pCi/l dissolved radium in Japanese rivers. Hursh's (1953) tabulation of 42 radium-226 observations made in water supply systems dominated by surface water as a source showed a geometric mean (GM) of 0.04 pCi/l. We conclude that surface water values for radium-226 are less than 0.1 pCi/l.

Ground water is generally higher in radium. Water supply systems in which excessive radium is present are typically ground-water dominated (Samuels, 1964). With respect to hydrogeologic factors and their influence on radium in ground water, Tokarev and Shcherbakov (1956) distinguished between sedimentary and siliceous igneous rocks and between circulating and stagnant aquifer systems. In sedimentary rocks, mean radium concentration in a circulating system is 2 pCi/l as opposed to 300 pCi/l in a stagnant system. Where siliceous igneous rocks are predominant, radium varies from 2 pCi/l in a circulating system to 4 pCi/l in a stagnant one.

TABLE 3. SUMMARY OF THE OCCURENCE OF DISSOLVED RADIUM IN WATER

MEDIUM	CONCENTRATION (pCi/l)	REFERENCE
WATER		
Ocean	0.07*	
Bottom	0.08 - 0.15	Koczy, 1958
Surface	.0001	Koczy, 1958
Mean	0.1*	Tokarev and Shcherbakov, 1956
FRESH WATER LAKES	1.0*	Tokarev and Shcherbakov, 1956
RIVERS	0.2*	Tokarev and Shcherbakov, 1956
Japan	0.08	Miyake et al., 1964
POTABLE WATER SUPPLY		
Surface Water	0.04**	Hursh, 1953
GROUND WATER		
Sedimentary Rocks		Tokarev and Shcherbakov, 1956
Circulating Water	2.0***	Tokarev and Shcherbakov, 1956
Stagnant Water	300***	Tokarev and Shcherbakov, 1956
Igneous Siliceous Rocks		
Circulating Water	2	Tokarev and Shcherbakov, 1956
Stagnant Water	4	Tokarev and Shcherbakov, 1956
UNITED STATES		
Conterminous	0.1 - 720	Scott and Barker, 1962
	0.15**	Present study; calculated from Scott and Barker, 1962
Atlantic and Gulf		
Coastal Plain	0.2**	Scott and Barker, 1962
Florida - Exclusive of central PO_4 District	0.2 - 12 1.0	Scott and Barker, 1962
Central Florida	1.0 - 15**	Present study

* Estimated mean
** Geometric mean
*** Arthmetic mean

Scott and Barker (1962) observed that radium in ground water in the conterminous United States ranged from less than 0.1 pCi/l to 720 pCi/l. Subdividing the United States into ten regions based on similarity of geologic physiographic, and ground-water conditions, they found that the geometric mean of six regions (Atlantic and Gulf Coastal Plain, Appalachian Orogenic Belt, Eastern Stable Region, Western Stable Region, Rocky Mountain Orogenic Belt, and Pacific Orogenic Belt) with adequate data varied from <0.1 pCi/l to 0.6 pCi/l. A log-normal probability plot of over 500 observations of radium data for ground water throughout the country reveals a geometric mean concentration of 0.15 pCi/l. The Atlantic and Gulf Coastal Plain Region (Plate I, Scott and Barker, 1962), which includes Florida, has a geometric mean of 0.2 pCi/l of radium. In general, ground-water values as determined for the United States have a geometric mean of about an order of magnitude larger than concentrations in surface waters.

FLORIDA GROUND WATER

Radium-226 data from areas outside the central Florida land pebble district were observed in 35 locations in 12 counties throughout the state (Figure 8). The plotted data are from Irwin and Hutchinson (1976) and open file data of the U.S. Geological Survey (Figure 9). The latter data, largely developed in the course of the Scott and Barker (1962) study, were supplied by R. C. Scott (Atascadero, California, written communication). Most of the Florida data reported by Scott and Barker are from flowing wells and are therefore not likely to be affected by wastewater or other surface sources of contamination. No attempt was made to separate the data according to aquifer or aquifer system. It is assumed that the radium present is from natural causes. No correlation of radium, with chloride, floride, uranium, or well depth is apparent.

The geometric mean radium concentration for background dissolved radium in Florida ground water is 1 pCi/l, with essentially all values falling in the range of 0.2 to 12 pCi/l. A near linear fit of the data on a log-normal probability plot suggests that the observations are part of the same population.

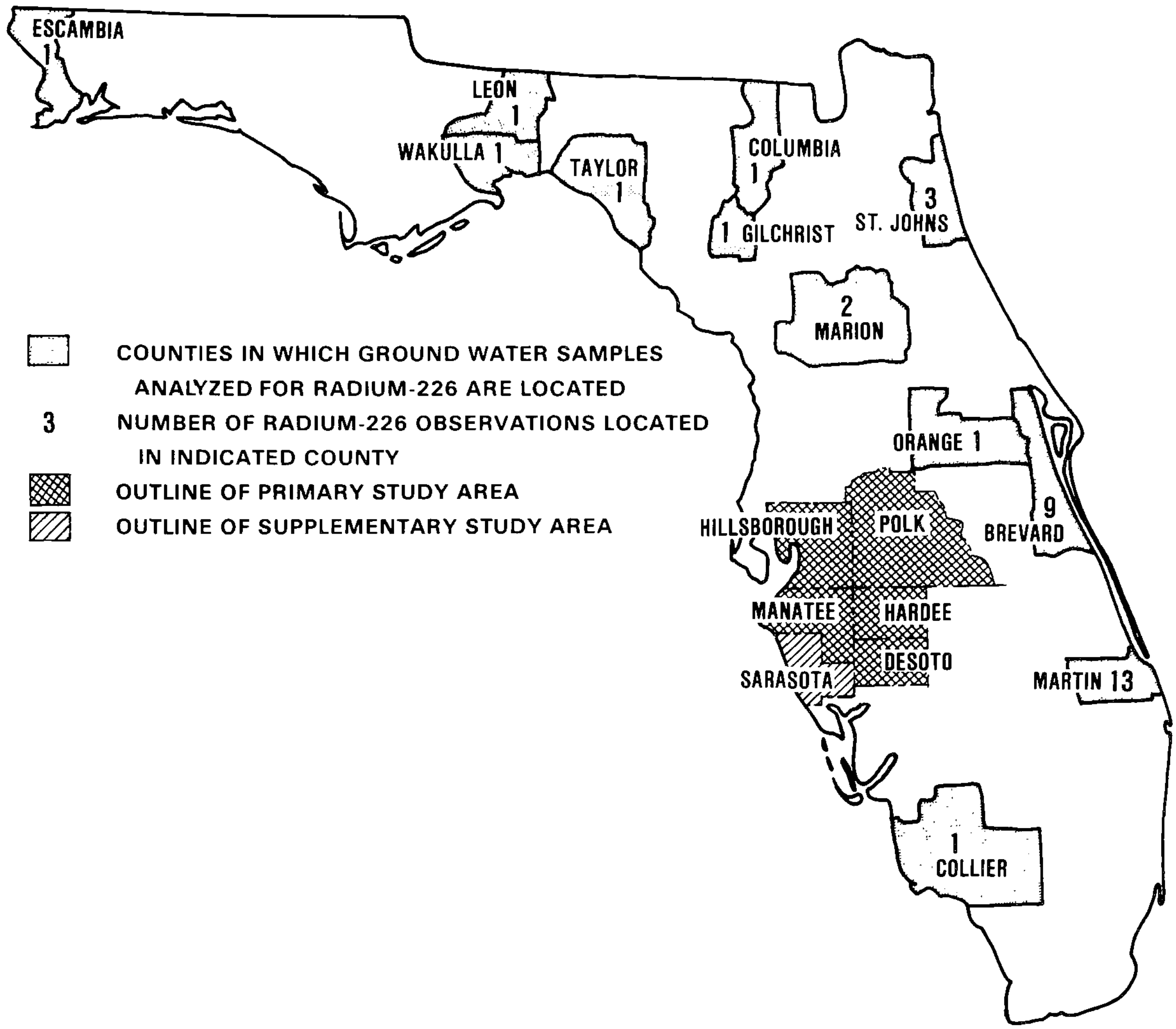


Figure 8. Location of counties used to establish background levels of radium-226 in Florida ground water.

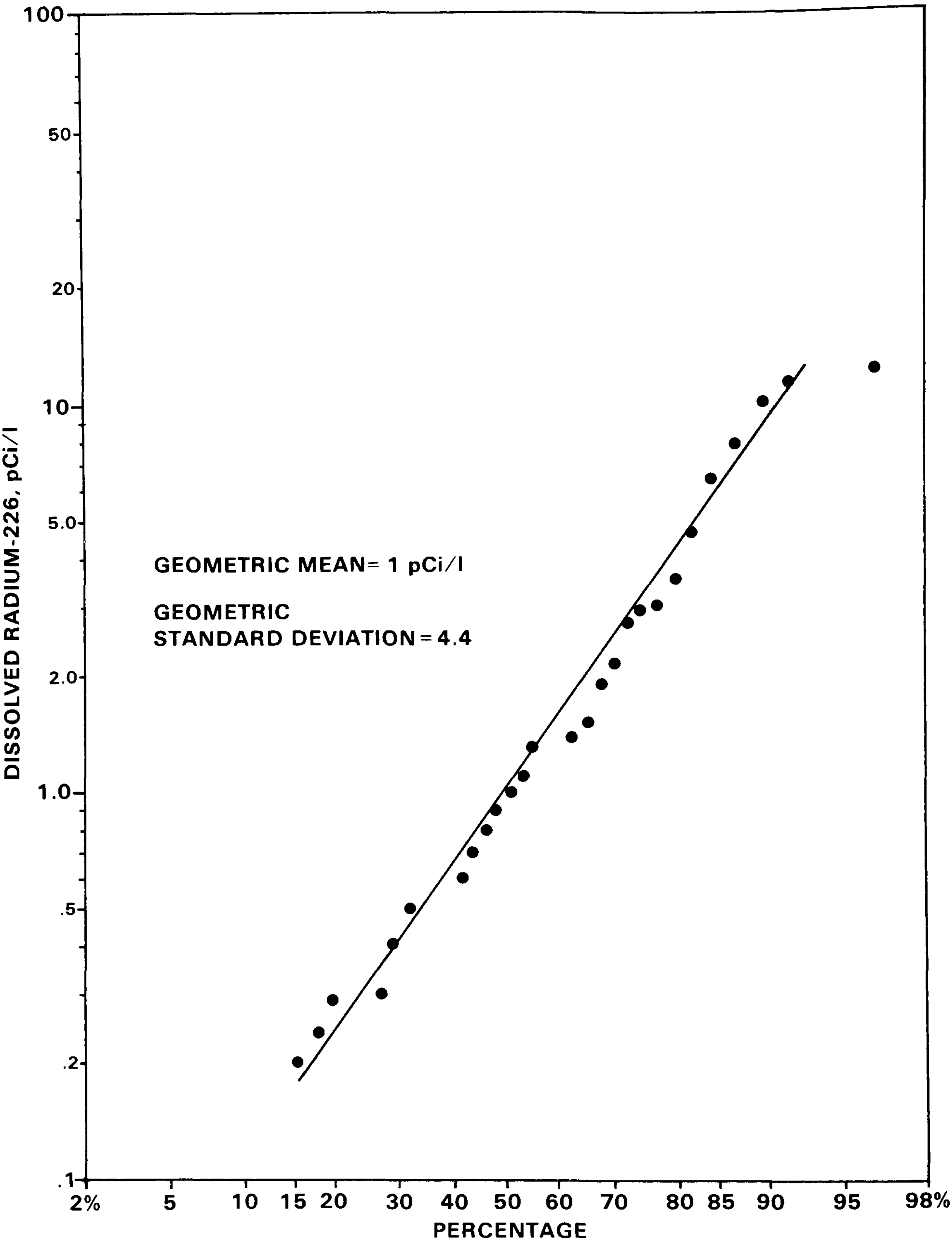


Figure 9. Log-probability plot of background levels of radium-226 in Florida ground water.

Assuming these data are reasonably representative of the radium-226 in Florida ground water exclusive of the central Florida land pebble phosphate district study area, the geometric mean is about one pCi/l or about an order of magnitude higher than the national geometric mean of 0.15 pCi/l, calculated from radium data presented by Scott and Barker (1962). Arithmetic and geometric means for radium in ground water for the study area in central Florida are higher yet, with averages typically ranging from 1.5 to 15 pCi/l. Since portions of Florida contain economic deposits of monazite sands which are enriched in thorium, radium-228 may also be elevated in associated ground water. Unfortunately, no radium-228 data are available for Florida ground water. In summary, there is good evidence that Florida ground water has naturally higher radium-226 levels than either the nation as a whole or the Atlantic and Gulf Coastal Plain region. With this introduction established, we will now focus on radium in ground water of central Florida.

WATER QUALITY EFFECTS OF PHOSPHATE MINERALIZATION AND THE PHOSPHATE INDUSTRY

As previously mentioned, data bases developed by FWPCA, USEPA, and USGS are available. Because of differences in analytical procedures, or time of sampling, the data bases were treated separately to analyze for spatial and temporal changes in ground-water quality. With respect to spatial variation, data availability as determined by aquifer and mineralization or mining status resulted in decidedly uneven coverage in certain categories. In order to make fullest use of the available data for 1973-1976 and also maintain analytical comparability, the data group with maximum observations, either USEPA or USGS, was selected for any given comparison of water quality according to aquifer, mining/nonmining, and mineralization criteria.

Three separate aquifers (water table, Upper Floridan, Lower Floridan) were considered for three separate land status categories (mined, unmined, and nonmineralized). Aquifer information was obtained by comparing well depth and casing information relative to hydrogeologic conditions, and from information presented in Irwin and Hutchinson (1976). Land use information was obtained from existing topographic maps, geologic reports, and mineral leasing records (W. Lancaster, Texas Instruments, Inc., written communication, April 1, 1977; Wayne Thomas, Inc., 1976). Aquifer and land use information for each sample is presented in Appendix 1.

STATISTICAL METHODOLOGY

Basic approaches taken to analyze the data include characterization of distributions, central tendency (mean, geometric mean), and variance (geometric standard deviation, standard deviation). With this information, nonparametric tests were selected to compare observations for significant difference as a function of time (1966 versus 1974-1976), space (mineralized, nonmineralized, etc.*), and depth (aquifer). Primarily because of the limited number of observations and therefore uncertainty concerning population distribution, nonparametric methods were used to analyze and compare variance and central tendency.

* Mineralized areas are defined as those within the pebble area (i.e., 55 percent or more BPL) of phosphate mineralization as mapped by Mansfield (1942, Plate 5). Locations of mined areas and plant sites appear on a detailed map by Wayne Thomas, Inc. (1976). Wells located in such areas or within one mile or less thereof are classified in the "mined" category.

Statistical analysis techniques often assume that the population or grouping of observations has a distribution which is known. If data are highly skewed with numerous small observations and several large ones, it may have a log-normal distribution (Koch and Link, 1970), i.e., the logarithms of the observations have a normal distribution. Trace elements, for example, are log-normally distributed (Ahrens, 1957) as are many types of environmental data (Denham and Waite, 1975). Therefore, it would be reasonable to expect trace amounts of radium-226 in ground water to be approximated by the log-normal distribution and a plot of such data is expected to have a linear appearance on log probability paper. The geometric mean equals the 50th cumulative percentile line, and the geometric standard deviation is defined by the line slope. At a geometric standard deviation of about 1.3 or less, skewness is sufficiently small that the population might be treated as normal without transforming the logarithms. Failure of a set of observations to approximate a log-normal distribution can be inferred using the Kolmogorov-Smirnov goodness-of-fit test. Denham and Waite (1975) suggest that when the plotted data have a linear trend, a single and presumably background population is depicted. Several line segments on a single log-normal probability plot suggest several overlapping populations, the distribution of which is unknown when few observations define a given line segment.

Log-normal probability plots of radium-226 data were extensively used to characterize several data sets in terms of geometric mean and geometric standard deviation for each aquifer or land category. In order to test possible relationships between the various groups of data which generally were not from a single, clearly defined distribution, "distribution-free" techniques of hypothesis testing were used. Two nonparametric statistical tests were used, the Mann-Whitney U test and the Kruskal-Wallis one-way analysis of variance (by ranks) test. The Mann-Whitney U test is a nonparametric analog of the student t test and can be used to determine if two independent groups were selected from the same population. A variant of the Mann-Whitney test (Springer, 1976) is used to validate a basic assumption of the test, i.e., whether both data sets are similarly dispersed. The Kruskal-Wallis test is a nonparametric analog to the parametric one-way analysis of variance or F test used to test dependency between three or more independent samples. A logical extension of the Kruskal-Wallis test, particularly when the ruling hypothesis is rejected, is to determine which groups are significantly different from one another. Gibbons (1976) suggests that simultaneous multiple comparisons is the best method for this, particularly as described in Dunn (1964). Since several simultaneous statements of difference are made, the level of significance used is larger so that a single difference is more likely to be detected. It is also quite possible that several groups may not be equal as indicated by the Kruskal-Wallis test but that simultaneous multiple comparisons may not find any pair with significant differences. Siegel (1956) and Gibbons (1976) give excellent examples and explanations on nonparametric statistics and should be consulted by those interested in exploring further into this subject.

SPATIAL VARIATIONS IN WATER QUALITY

Table 4 summarizes the number of observations by source (USEPA, USGS), range, mean, and standard deviation for the land categories and aquifers considered. The USGS data were used to analyze the water table aquifer and Upper Floridan aquifer and USEPA data were used for the Lower Floridan aquifer. Temporal changes in water quality are discussed in a subsequent section.

Water Table Aquifer

Unfortunately, radium-226 data for the water table aquifer is restricted to mineralized areas with no information available in the nonmineralized portions of the study area (Table 4). For 23 observations in the mineralized unmined area the geometric mean (GM) is 0.17 pCi/l and the geometric standard deviation 12.9. The observations show pronounced linearity on log probability paper (Figure 10), suggesting a log-normal population. This, however, was rejected by the Kolmogorov-Smirnov goodness-of-fit test at the 95 percent confidence level. Three of the 23 observations exceed the 5 pCi/l combined radium-226 and radium-228 standard for community water systems (U.S. Environmental Protection Agency, 1976a).

TABLE 4. SUMMARY OF AVAILABLE RADIUM-226 DATA AND STATISTICS

Key: upper right of each cell = 1973-1976 EPA DATA (NO., MEAN, SD, RANGE); lower left of each cell = 1974-1976 USGS DATA (NO., MEAN, SD, RANGE); black corner = DATA SET USED IN ANALYSIS.

		AQUIFER			
			WATER TABLE	UPPER FLORIDAN	LOWER FLORIDAN
MINERALIZED	UNMINED	1973-1976 EPA DATA (NO. / MEAN / SD / RANGE)	3 / 1.63 / 1.56 / .2-3.3	9 / 3.06 / 3.35 / .18-10.6	24 / 2.0 / 2.3 / .19-15.3 (used in analysis)
		1974-1976 USGS DATA (NO. / MEAN / SD / RANGE)	23 / .17 / 12.9 / .05-22.0 (used in analysis)	5 / 2.30 / 3.35 / .24-7.7 (used in analysis)	9 / 1.4 / 1.3 / .06-4.7
	MINED	1973-1976 EPA DATA (NO. / MEAN / SD / RANGE)	4 / 2.80 / 1.65 / 2.0-5.3	NO DATA	6 / 1.96 / 1.33 / .13-3.5 (used in analysis)
		1974-1976 USGS DATA (NO. / MEAN / SD / RANGE)	12 / .55 / 3.3 / .20-4.4 (used in analysis)	10 / 1.61 / 2.0 / .16-6.0 (used in analysis)	7 / 4.49 / 6.51 / .14-14.0
NONMINERALIZED (CONTROL)		1973-1976 EPA DATA (NO. / MEAN / SD / RANGE)	NO DATA	NO DATA	14 / 1.4 / 2.5 / .23-14.7 (used in analysis)
		1974-1976 USGS DATA (NO. / MEAN / SD / RANGE)	NO DATA	3 / 5.1 / 4.3 / .20-7.9 (used in analysis)	2 / 2.8 / 1.4 / 1.8-3.8

COMBINED EPA DATA (Lower Floridan, mineralized unmined and mined): 30 / 1.9 / 1.9 / .13-15.3

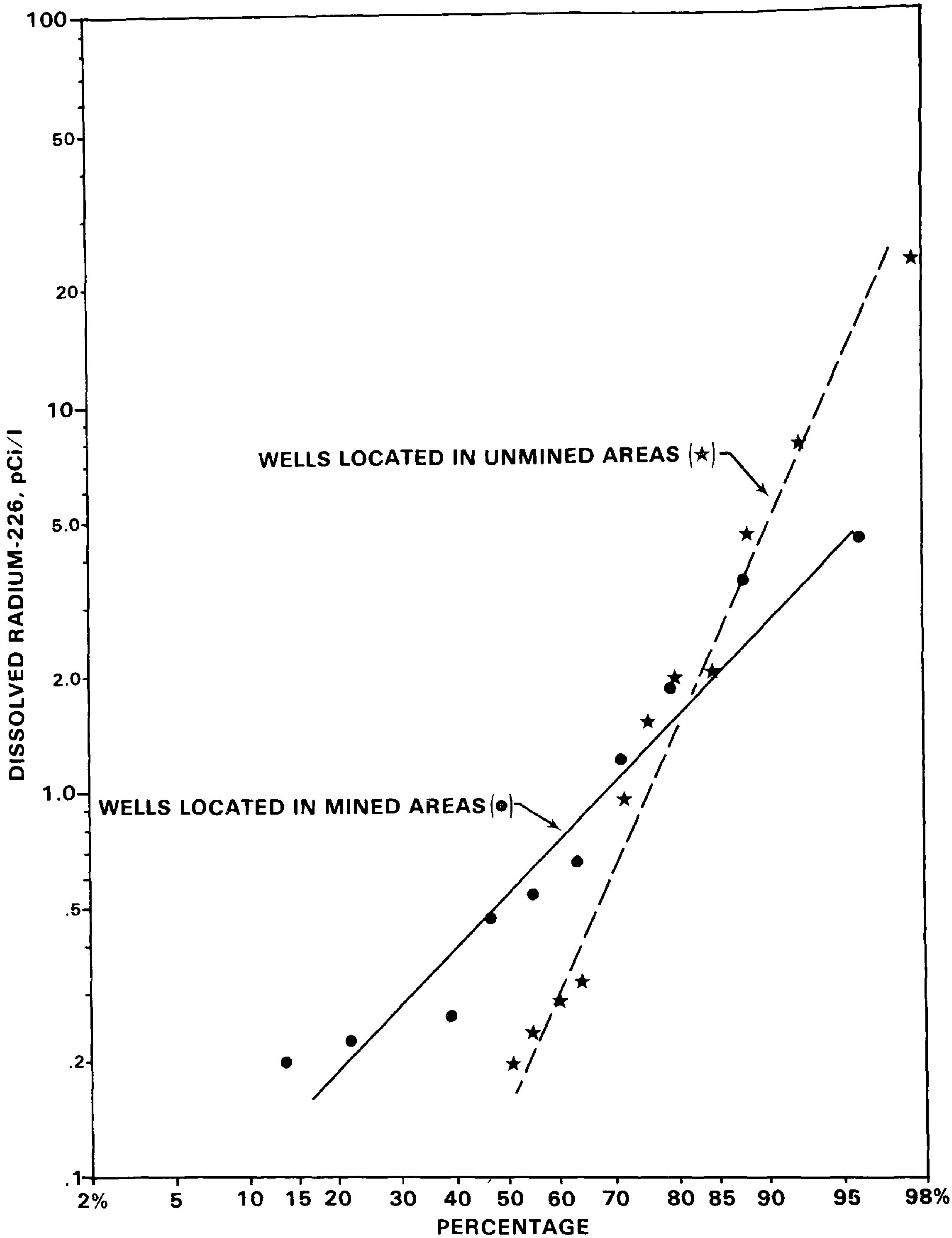


Figure 10. Log-probability plots of USGS data for the water table aquifer in unmined and mined mineralized areas.

For 12 observations in the mined mineralized area, the GM is 0.55 and GSD is 3.3, indicating a population which is much less skewed than in the mineralized unmined area (Figure 10) but is similar in having a strong linear trend. That radium in mined, mineralized areas is log-normally distributed can not be rejected by the Kolomogorov-Smirnov goodness-of-fit test at the 95 percent confidence level. None of the observations exceed 5 pCi/l for radium-226. No radium-228 data are available to confirm whether combined radium-226 plus -228 exceeds the 5 pCi/l limit established by USEPA for public water supplies.

In order to determine whether these two data sets are in fact from the same population, a "distribution-free" method of comparison was used. For testing whether two groups are equally likely to have been taken from the same population, the nonparametric Mann-Whitney U test is quite effective (Siegel, 1956). Using a method described by Springer (1976), the observations in both data sets were first tested for similar dispersion, a prerequisite assumption for use of the Mann-Whitney test. Dispersions or variances are similar at the 95 percent confidence level. The test value or "Z" statistic generated by the Mann-Whitney test was 1.01. This value is too small to reject the null (ruling) hypothesis at the 95 percent confidence level. Therefore, the two samples appear to have been taken from the same population. Based on these data and the analysis described, no impact on the water table aquifer appears to have occurred as a result of mining.

Upper Floridan Aquifer

As the USGS data base has observations in all three land classification groups, it was selected to characterize radium-226 in the Upper Floridan aquifer. All groups had 10 or less observations and no attempt was made to plot on log probability paper. Statistical parameters used to express central tendency and standard deviation are arithmetic (Table 4). In areas of mineralization without mining, one out of the five observations is greater than 5 pCi/l. In areas subject to the impact of mining, one out of ten observations is greater than 5 pCi/l. Of the three observations in the mineralized area, two are greater than 5 pCi/l. To test whether these three groups are part of the same population, the Kruskal-Wallis one-way analysis of variance test was used, yielding a test value for H of 52.37 . The probability of H this large due to random chance is less than 0.001, inferring that the three groups are not equal. Using simultaneous multiple comparisons, at the 80 percent confidence level, only the mined versus nonmineralized groups are significantly different whereas for the nonmineralized area, mean radium-226 is greater than that in mined areas. Based on these data and analysis, no impact on the Upper Floridan aquifer seems to have occurred as a result of mining and related waste management.

Lower Floridan Aquifer

The USEPA data base was used to characterize the radium-226 in the Lower Floridan aquifer. Two groups, mineralized unmined and unmineralized, have the greatest number of observations, 24 and 14 (Table 3). A log-normal probability plot of dissolved radium-226 in the mineralized unmined area exhibit three distinct line segments. This pattern remains if the six observations from the mined area are included (Figure 11). They were included because they are evenly distributed within the range of values for the mineralized unmined area. A very similar alignment of line segments also characterizes the Lower Floridan in areas of nonmineralization (Figure 11). This suggests that radium in the Lower Floridan aquifer is not related to phosphate mineralization.

Although only 4 of the 24 observations in the unmined, mineralized areas exceed 5 pCi/l for radium-226, other samples with lesser concentrations might also exceed the USEPA standard of 5 pCi/l radium-226 plus radium-228. In the mined area none of the six samples contained over 5 pCi/l radium-226 whereas in the nonmineralized area, one well of 14 sampled exceeded 5 pCi/l. Again, radium-228 data are unavailable. On the basis of available radium-226 data, phosphate mining and processing do not appear to have deteriorated the quality of water in the Lower Floridan.

The visual similarity in the plots for data from mineralized and non-mineralized areas is inferred by the Mann-Whitney U test, which has a test "Z" value of 0.08. This has an associated probability of 0.47, clearly much

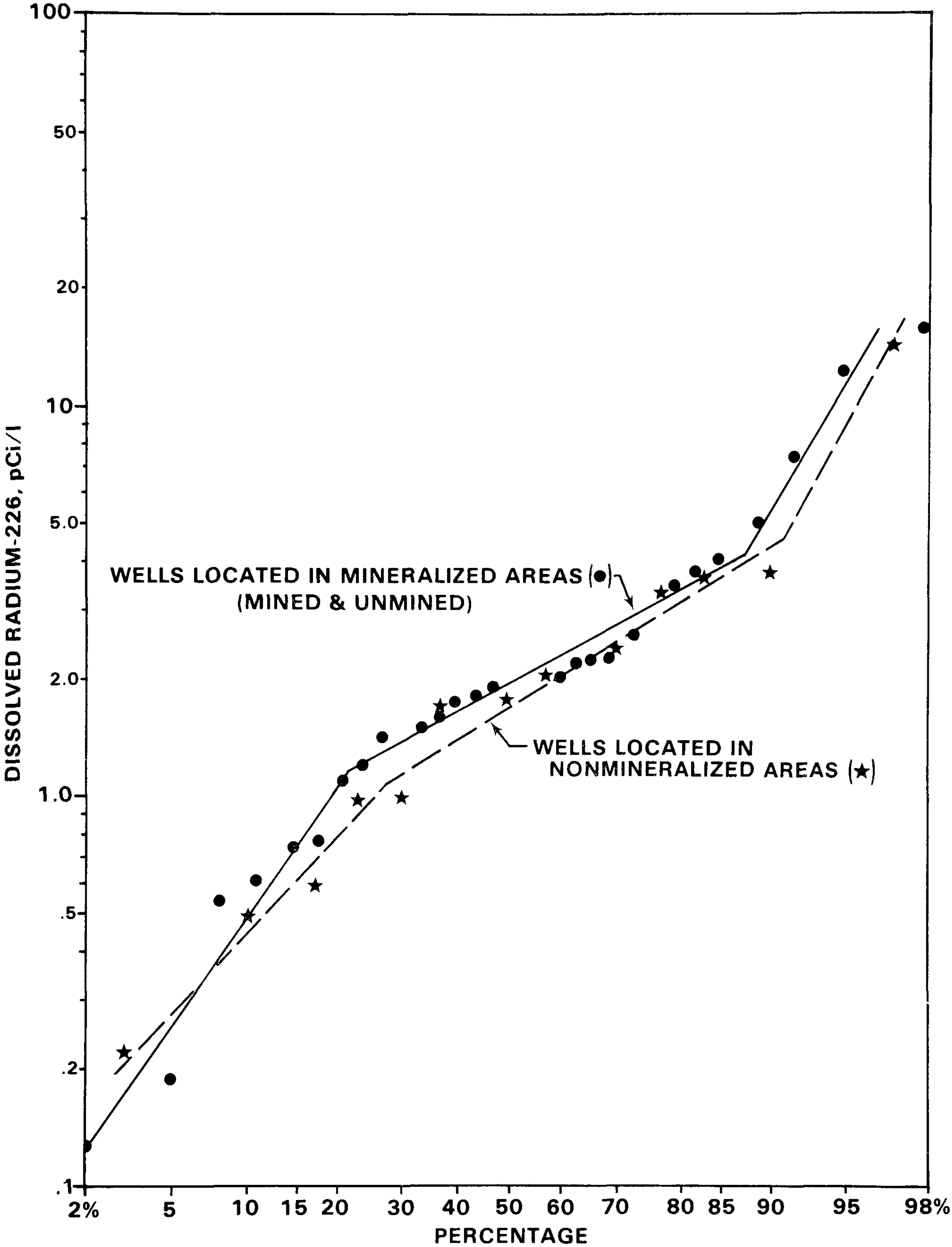


Figure 11. Log-probability plot of USEPA data for the Lower Floridan aquifer in mined and unmined mineralized areas and in nonmineralized areas.

greater than the pre-set alpha of 0.05. Therefore, the ruling hypothesis is accepted, i.e., there is no significant difference in radium content of ground water in mineralized versus nonmineralized areas.

Plots of dissolved radium-226 data for the Lower Floridan aquifer suggest the presence of three separate populations. Grouping all the radium-226 into a single log probability plot and using graphical techniques described by Sinclair (1974), the curve was partitioned into three parent populations as shown in Figure 12. The three populations were combined in proportion to their presence to generate the observed plot. Population B is dominant. It represents 52 percent of the total observations and has a GM of about 3 pCi/l. About 10 percent of population B observations are suggested to exceed the 5 pCi/l limit. Population A is second most abundant, contributing 37 percent of the observed radium-226 values. With a GM of about 0.7 pCi/l, this population will have on the order of one percent of its observations exceeding the 5 pCi/l limit. Population C, representing about 11 percent of the total observations, has a GM of 10 pCi/l and has about ninety percent of its values above the 5 pCi/l level. All of population C observations were taken outside the areas defined to be influenced by mining.

Clearly the Lower Floridan aquifer is a complex system with radium-226 distribution dependent on several processes and/or sources. Much more detailed information on water chemistry, lithologic composition, and hydrology would be required in order to attempt to define the underlying reason for these suggested populations. Modification in the chemical and physical processes in the Lower Floridan aquifer so as to enhance the content of dissolved radium to the level typified by population C would be highly undesirable. We conclude there are occasional high radium-226 observations in ground water from the Lower Floridan aquifer associated with natural factors essentially unrelated to phosphate mineralization or the central Florida phosphate industry.

Elevated levels of radium-226 in the Lower Floridan aquifer can be due to a number of natural factors unrelated to phosphate mineralization or waste management in the phosphate industry. Increased solubility of radium occurs in ground water enriched in chloride (Tanner, 1964). Kaufman and Dion (1967) have shown that upwelling of mineralized water occurs along the trace of the

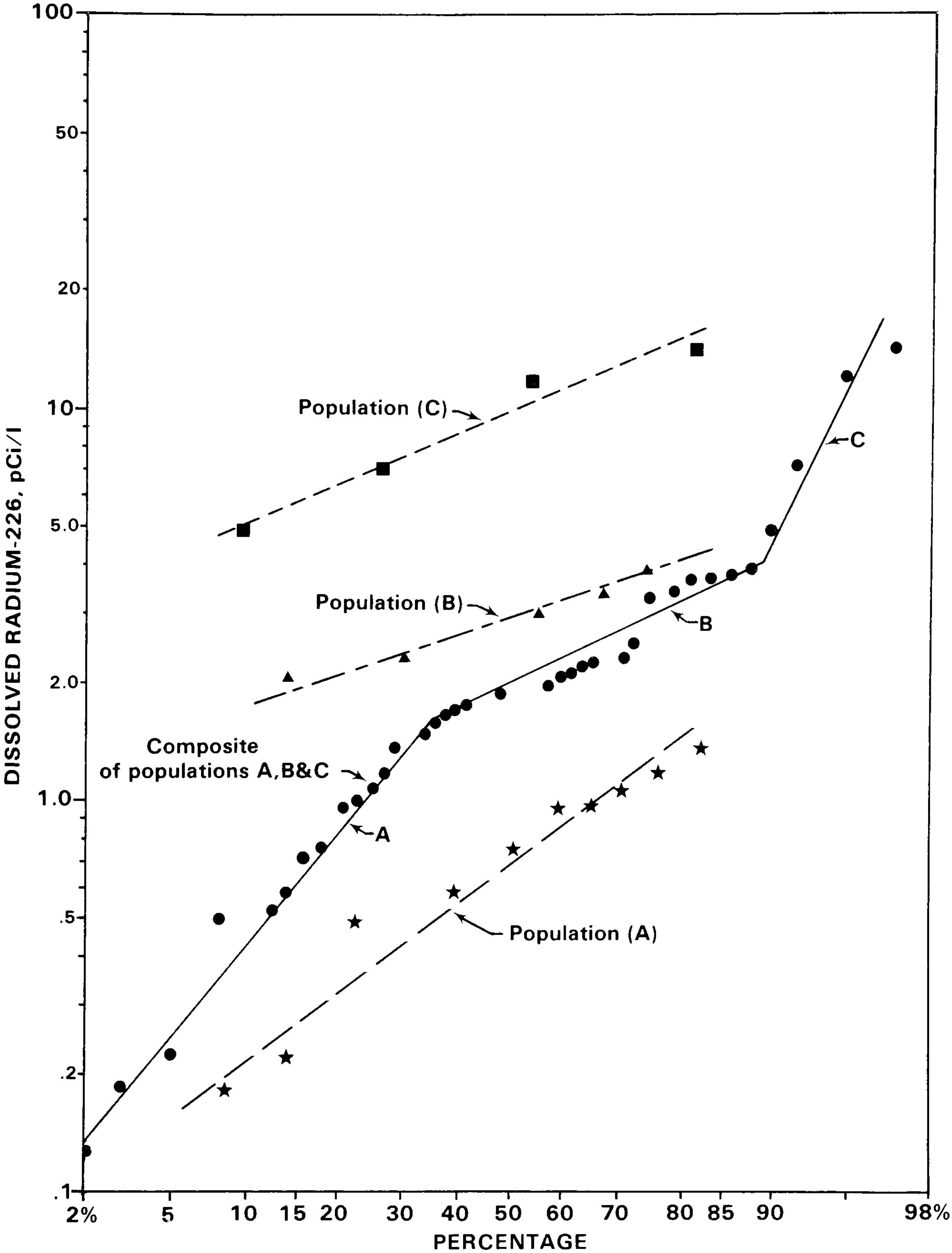


Figure 12. Component populations of radium-226 in the Lower Floridan aquifer of central Florida.

southern Peace River. Widespread, pronounced reduction of the potentiometric surface for the Lower Floridan aquifer is well documented and problems of water supply and water quality are receiving increasing attention in central Florida. Sea water encroachment and upwelling of deeper more mineralized ground water in cones of depression due to pumping from the Lower Floridan aquifer, particularly the Avon Park Limestone, are of particular concern. Whether heavy pumping of the Floridan aquifer will actually induce upward movement of more saline, possibly radium-enriched water is an unanswered question and probably one which will require much additional data and interpretation.

Dissolved gross alpha radioactivity values for 10 wells in Manatee County, 9 of which are for domestic use, are less than 2 pCi/l in all cases (See Figure 7). The wells tap the Floridan aquifer which is undifferentiated as to Lower and Upper because of the absence of a prominent aquitard at the base of the Tampa Formation in this area (Wilson, 1975). Because the correlation between dissolved radium and gross alpha is rather inconsistent, particularly at low concentrations and because dissolved radon accounts for most of the alpha activity, the Southwest Florida Water Management District has gradually increased the gross alpha threshold from 2 to 5 pCi/l and then from 5 to 15 pCi/l as the basis for requiring analysis for radium-226 (B. Boatwright, SWFWMD, personal communication, May 31, 1977). That is, below 15 pCi/l gross alpha, radium is believed to be present in acceptable levels of 5 pCi/l or less. For this reason, values of 2 pCi/l gross alpha in the Manatee County wells for which only gross alpha data are reported on herein, are believed to contain very low concentrations of radium-226.

Mean radium content in seven Manatee County wells tapping the Floridan aquifer was 4.52 pCi/l versus 1.23 pCi/l from three water table wells. Radium varied from 0.11 to 3.7 (mean 1.94) in six wells of unknown depth or production interval. In general, radium increases with depth. There was no phosphate mining at the time of sampling; hence, this source is discounted and natural factors other than the phosphate industry are believed responsible for high radium values observed. This is reinforced by the fact that half of the wells with values exceeding 3 pCi/l are located in areas not considered ore bearing.

In summary, the statistical analysis techniques utilizing available data and the conclusions therefrom are probabilistic in nature. There is neither "proof", per se, for the conclusions herein nor can they be considered final. Qualification of the available data is a necessary procedure designed to put the interpretations into proper context but without necessarily discrediting the conclusions. The exact extent to which phosphate mineralization causes elevated radium-226 in the three aquifers considered is not readily discernible. This is due in part to lack of observations in the water table in nonmineralized areas and the availability of only three observations for the Upper Floridan aquifer for the same areas. Theoretically, phosphate mineralization should be a radium-226 source for the Upper Floridan aquifer due to the intimate association of aquifer and ore body. However, there are too few data to make meaningful comparisons on the basis of land use or mineralization.

Under natural conditions the water table aquifer is perhaps not as closely associated with phosphate mineralization as is the Upper Floridan. However, disturbance by phosphate mining directly disrupts the water table aquifer. Overburden and wastes associated with benefaction and chemical processing have the potential for introducing radium into both aquifers. Yet, radium-226 data suggest that mining has not appreciably changed radium-226 levels in the water table. Again, this conclusion is probabilistic, being based on statistical analysis of available data. To presume no change is occurring may well be erroneous. Ground-water dynamics are greatly affected by mining, as is the lithological sequence, the matrix and leach zone portions of which have a potential for contributing radium-226 to ground water. It is difficult to believe that change is not underway.

On the basis of the data presented herein, radium-226 in the Lower Floridan aquifer appears to bear no relation to the effects of land use or the presence/absence of phosphate mineralization. The distribution pattern of radium data on log-probability plots suggests a complex system and possibly multiple populations, probably stimulated by natural factors unrelated to phosphate deposits or the industry. In general, radium-226 levels below mineralized areas are low. Possibly radium-226 is depleted as a result of mineralized areas are low. Possibly radium-226 is depleted as a result of dilution and sorption in overlying strata and aquifers. Although the data are limited and numerous exceptions are present, radium-226 generally increases with salinity which, in turn, varies with well depth and position in the flow regime within the Floridan aquifer system. Radium-226 concentrations of 10-20 pCi/l may be associated with more mineralized or brackish ground water in the deeper parts of the aquifer. Whether altered flow patterns are present due to pumping and whether such patterns can induce upwelling of water with higher radium content are unanswered questions.

The existing radium-226 data base is marginal in terms of number and spatial distribution of analyses, particularly for the water table and Upper Floridan aquifers. Aquifer system complexity and widespread changes in land use require a greatly increased sampling program if these variable are to be considered. Inconsistency in study objectives and analytical procedures and lack of overlap between the USGS and USEPA data bases on a well-by-well basis, or even by aquifer, restrict reaching precise definition of spatial changes in radium-226 content of ground water.

SARASOTA COUNTY

Because of its location at the extreme southern end of the Central Floridan phosphate district and closeness to the discharge portion of regional ground-water flow within the Floridan aquifer system, Sarasota County radium-226 data are considered separately. Radium-226 data for untreated water from public and private wells are shown in Appendix 4. Locations are shown on Figure 13. Most wells are completed in both the water table aquifer and Floridan aquifers. Clear distinction between Upper and Lower Floridan aquifers on the basis of available stratigraphic information was not considered feasible for Sarasota County. All 12 observations in the water table aquifer have radium-226 concentrations greater than 5 pCi/l with a geometric mean of about 15 pCi/l (see Figure 14). In comparison, the Floridan aquifer has generally lower radium-226 concentrations, although 70 percent of the observations also exceed the 5 pCi/l level. Geometric mean radium content is about 7.5 pCi/l. Radium in the water table and Floridan aquifers probably represents two independent

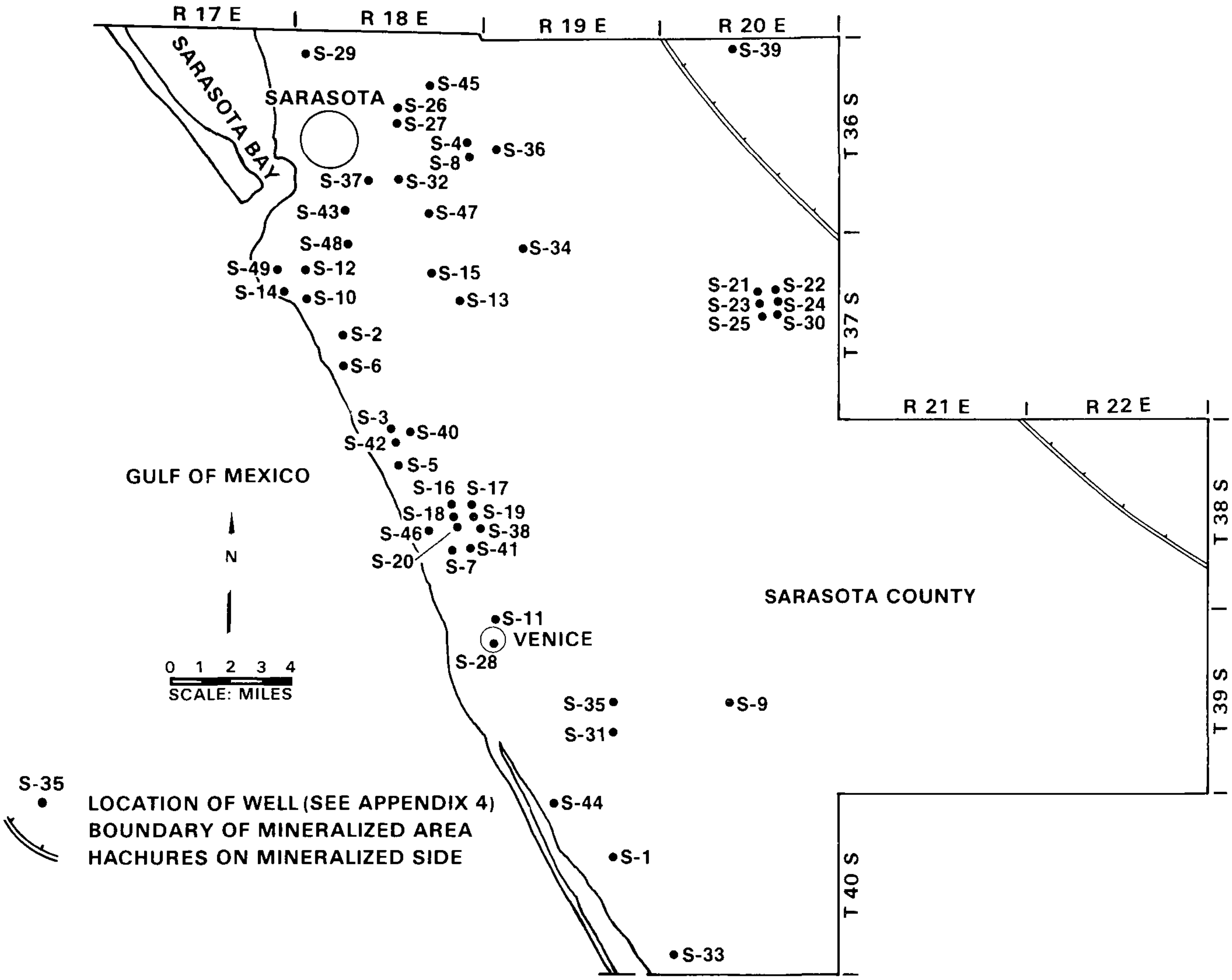


Figure 13. Location of wells sampled for radium-226 in Sarasota County.

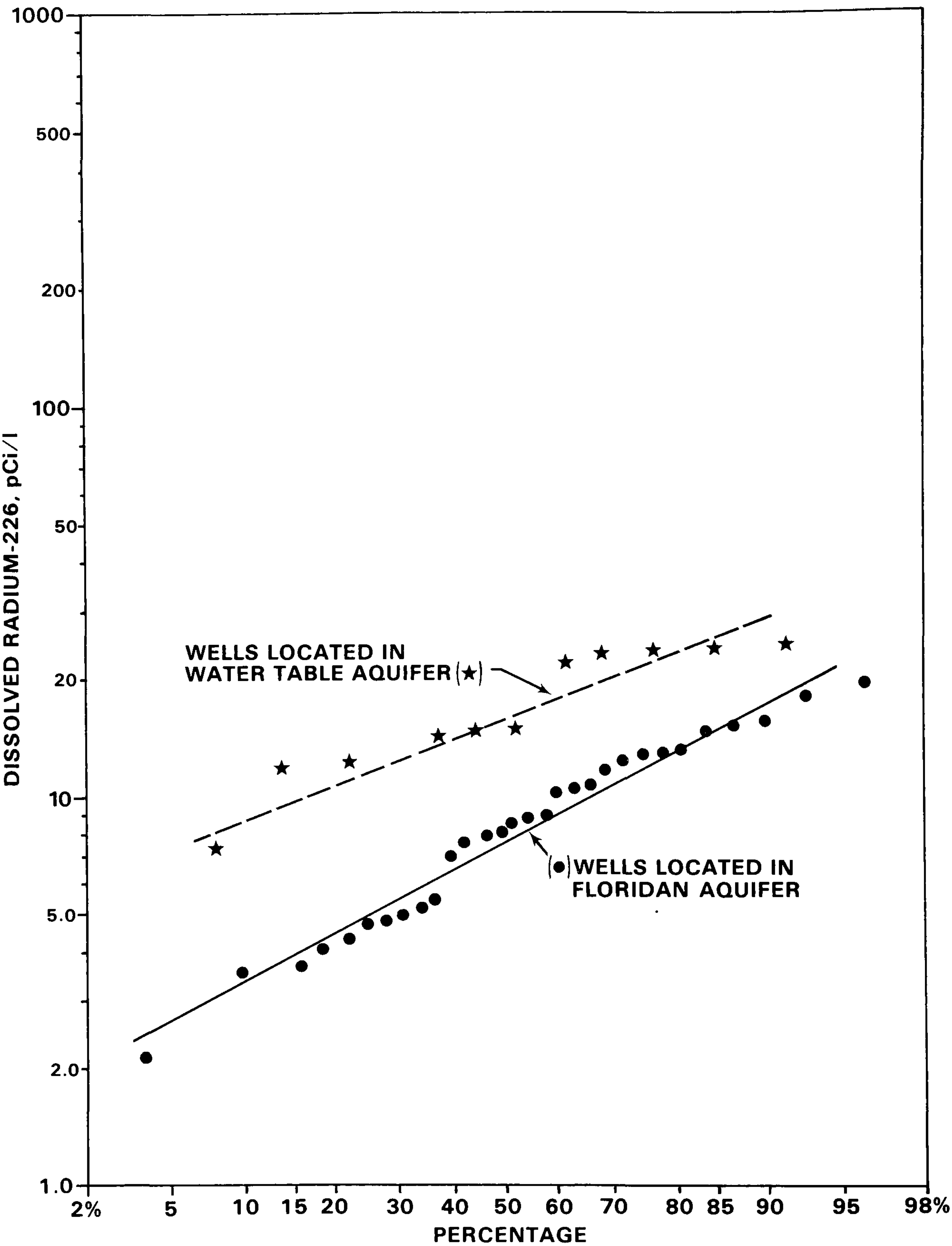


Figure 14. Log-probability plot of radium-226 in the water table and Floridan aquifers, Sarasota County.

populations. After testing the data sets for similar dispersion, the Mann-Whitney test produced a test value for "Z" of 3.57 with associated probability much less than the pre-set alpha of 0.05. This indicates that the two groups are probably significantly different and that the water table aquifer has significantly greater radium-226 than the Floridan.

Most of the data for the water table aquifer occur in two areas: 1) within a mile of the Gulf Coast, midway between Venice and Sarasota, and 2) in the area centered in the Myakka River State Park in the northeast part of the county adjacent to Manatee County (Figure 15). The coastal wells have significantly greater radium-226 (mean = 20.8 pCi/l) than inland wells (mean = 13.6 pCi/l) on the basis of the Mann-Whitney test at the 95 percent confidence level. Observations of radium-226 in the Floridan aquifer are largely confined to a mile-wide strip running parallel to the general trend of the coast. Isopleths of radium-226 on the basis of a 5 pCi/l contour interval (Figure 16) suggest that ground water in areas immediately adjacent and within about one-eighth mile of the coast contains 5 pCi/l or less radium-226. Paralleling this zone is a second one wherein radium exceeds 15 pCi/l. The inferred radium-226 high appears to trend eastward and away from the city of Sarasota in the northern part of the county, possibly extending into south-central Manatee County.

Inland of the coastal zone just described there are insufficient data to characterize radium in the Floridan aquifer. As shown in Figure 16, levels east of Venice and southeast of Sarasota are 5 pCi/l or less but may well be higher in the area between, as well as in the southern tip of the county. There are no data for the eastern two-thirds of the county.

Clearly radium-226 in ground water in Sarasota County is considerably above levels observed in Polk County and surrounding counties of the primary study area. This is true for the water table and Floridan aquifers. The Hawthorn Formation, the principal phosphate-bearing formation in the area, crops out in the northern part of the county and extends toward the coast (Mansfield, 1942), where it again crops out or is within 20 feet of the land surface (Sarasota County Health Department, 1976). In terms of phosphate content, the Hawthorn is quite low, relative to the Polk County and surrounding area.

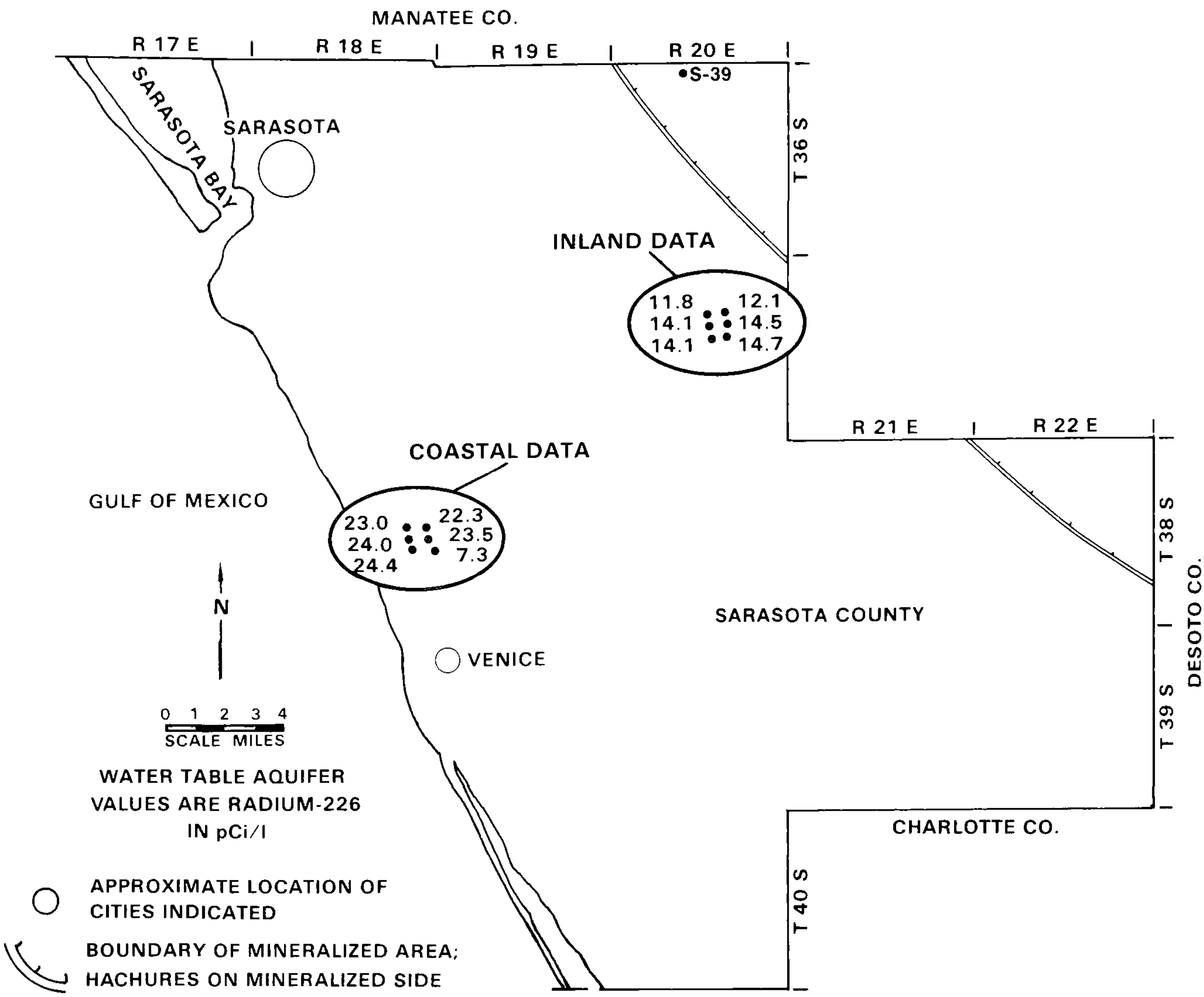


Figure 15. Location of radium-226 observations in the water table aquifer in Sarasota County.

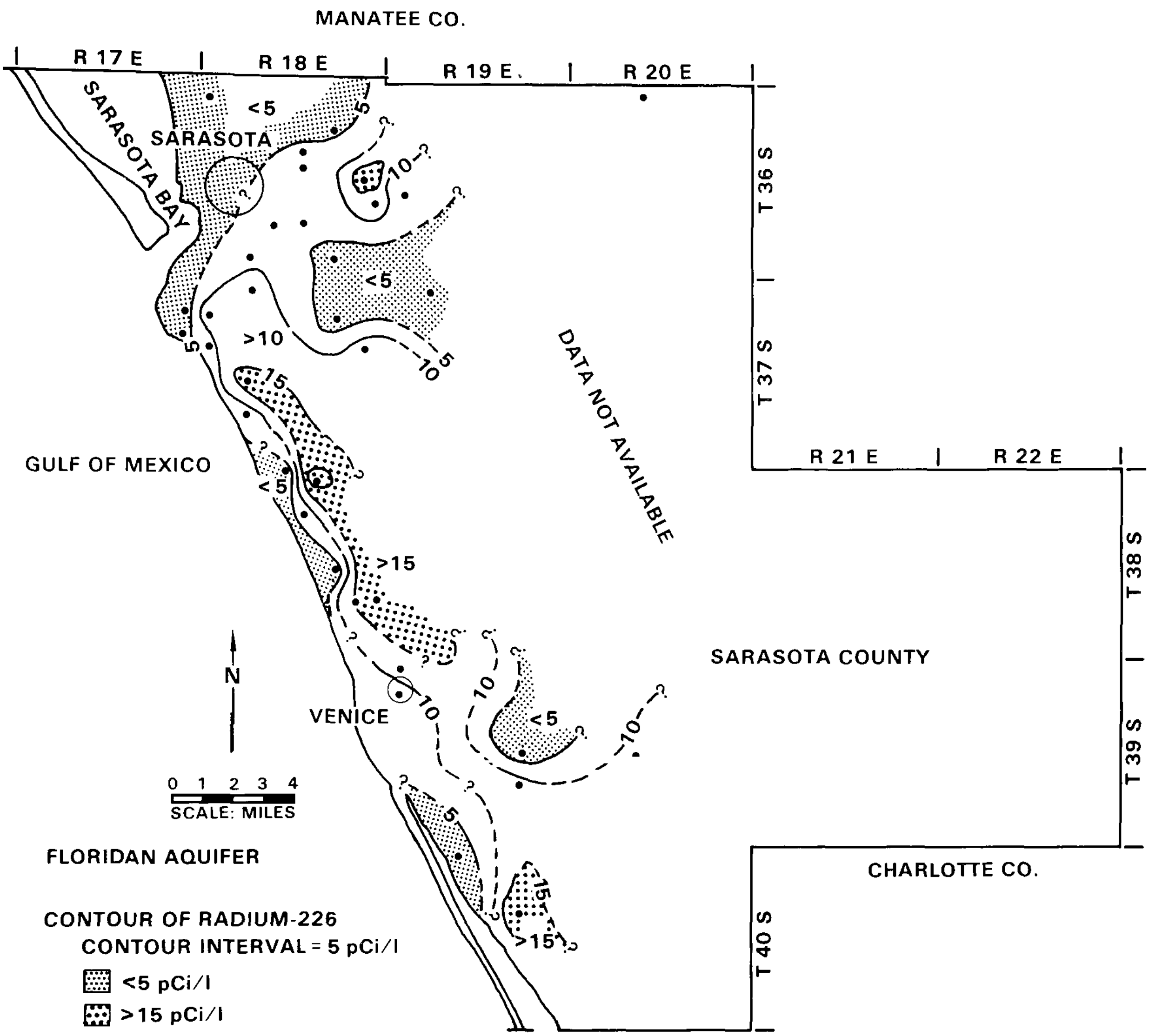


Figure 16. Contour map of radium-226 in the Floridan aquifer in Sarasota County.

Another potential radium source in Sarasota County is monazite sand. Overstreet (1967) noted large amounts of localized heavy mineral sands in beaches near Venice in Sarasota County. Analysis of these sands (Florida Department of Health and Rehabilitative Services, 1976) as a part of a study of radiation in Sarasota County revealed 0.05 to 1.5 percent monazite, a cerium-lanthanum phosphate containing minor thorium-232, the parent of radium-228. Additional analysis for radium-228 in Sarasota County ground water is strongly recommended, particularly in the water table aquifer.

Why does Sarasota County ground water have such high radium-226 levels? A possible answer may be suggested by exploring some facts about the general chemical status of the Floridan aquifer, radium geochemistry, and regional ground-water dynamics. First, what are some of the chemical attributes of the Floridan aquifer? Back (1969) lumped the Floridan aquifers into a single system and observed that the system is characterized by low total dissolved solids near the piezometric high in Polk County, with an increase in all directions toward the coasts and Lake Okeechobee. In fact, all fresh water in Florida is underlain by saline water which ranges in depth from 700 meters in the central part of the peninsula to near sea level along some shorelines. Ground water becomes increasingly enriched in chloride, sulfate, calcium, and magnesium as the coastal areas are approached. Back also noted that the increase in these constitutents is not simply due to mixing fresh water and ocean water as there is too much calcium and carbonate and too little sodium. Increasing amounts of limestone are going into solution with the increased salinity. Similar increases in concentration are observed for magnesium and sulfate.

How these factors influence radium-226 movement is evident from the fact that radium is an alkaline earth with behavior similar to that of calcium, strontium, and barium. However it is somewhat less mobile. Radium solubility in solutions is enhanced at high and low values of pH. Dissolution of radium is most enhanced by common cations already in solution. Of these Na^+ is most important, followed by K^+ and Ca^{2+}. Tanner (1964) observed that chloride-rich waters are either enriched in radium or have greater capability for leaching radium.

It is quite possible that increased concentrations of dissolved solids and calcium in particular, in the Floridan aquifer could help mobilize radium in the coastal areas. Secondly, the Hawthorn, though not normally viewed as a major component of phosphate reserves in the specific study area, apparently contains sufficient phosphate and associated radionuclides that chemically active ground water can leach out radium-226. Correlation of radium-226 with undissolved solids is modest ($r = 0.59$) in Sarasota County ground water. However, the correlation of radium-226 concentrations with total dissolved solids is quite strong ($r = 0.82$, Figure 17), tending to support a cause-effect relationship between dissolved solids and radium. Regression analysis of available Sarasota County data suggests that for every additional 100 mg/l dissolved solids, radium-226 increases about 1 pCi/l.

Several points should be considered concerning the influence of ground water movement on radium content of Sarasota County ground water. The county is clearly an area of discharge as viewed regionally. Ground-water development is relatively light and flow directions are expected to be upward and toward the coast. One available analysis of radium from a well completed deep in the Floridan aquifer contains 21.7 pCi/l radium and is high in dissolved solids. This possibly suggests that radium-226 levels in ground water can also be high without direct leaching of the Hawthorn Formation. Various speculations concerning the source of radium in deep, mineralized ground water have been offered. Leaching of crystalline basement rocks is favored but the mechanics are unknown. It is reasonable to assume that shallow, phosphatic sediments are not the source of radium in deep ground water.

Utilization of ground water from the Floridan aquifer for domestic and municipal water supplies in Sarasota County is hampered by the high total dissolved solids. To what extent radium exceeds 5 pCi/l and is therefore also a limitation is unknown and worthy of additional data collection. If radium concentrations are at or near the 5 pCi/l limit in those areas of the county where no data are now available, extensive and rather refined monitoring is recommended to insure that ground-water quality is preserved and possibly enhanced as a result of any major land or water use activities and particularly phosphate mining and chemical processing.

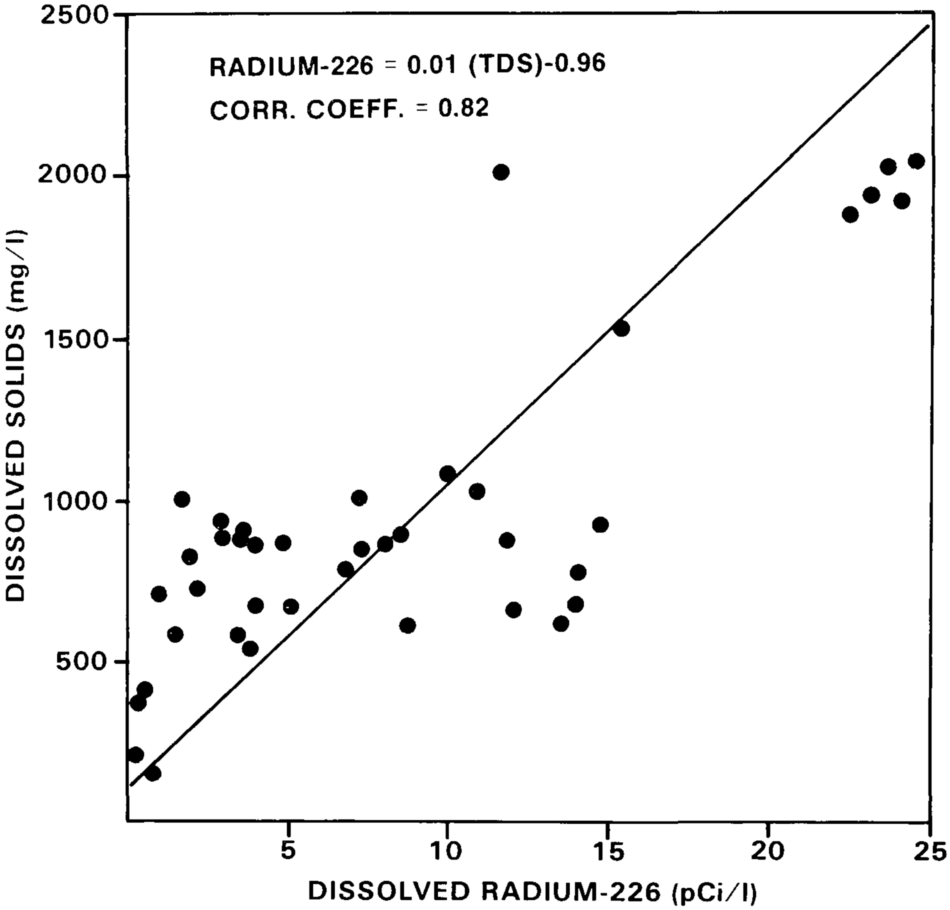


Figure 17. Plot of dissolved solids versus radium-226 in Sarasota County ground water.

TEMPORAL CHANGES IN WATER QUALITY

Wells sampled in both the 1966 survey and again in 1974-1976 (USGS data for unacidified samples only; Appendix 1) were checked to ascertain if temporal changes in water quality could be identified for the three principal aquifers. The USGS data for unacidified, filtered samples are considered more comparable to the 1966 FWPCA survey data developed from samples which were filtered and then acidified. By comparison, the USEPA data shown in Appendix 1 are from samples which were acidified, mixed, allowed to stand for dissolution of solids, and then filtered. This is believed to produce generally higher values for dissolved radium.

Efforts to match identical or similar (in terms of location and producing aquifer) wells using the 1966 FWPCA survey and the 1974-1976 USGS survey were disappointing in that only two data pairs involving similar wells could be identified. Data interpretation of significance for such a small sample set is deemed of no significance. Comparison of the 1966 survey with the 1973-1976 USEPA data base revealed eight paired sets involving 18 wells. Only 2 of the 8 pairs involved identical wells. Unfortunately, the USEPA data are not considered comparable to the FWPCA data because of differences in pre-analysis procedures.

For the area considered to be mineralized (see Figures 6 and 7), analyses were selected from the 1966 survey and from the 1974-1976 USGS survey. Using the Kruskal-Wallis test (Siegel, 1956), the six data sets as defined by three aquifers and two sampling periods (see Table 5) were evaluated to determine whether they were homogeneous. A test value "H" of 291.35 strongly suggests that the six data sets are not all equal. Is this inequality due to differences exhibited for an aquifer between the two periods of sampling? Using the simultaneous multiple comparisons test, (Gibson, 1976) between data pairs defined by time in each aquifer, no significance was determined at the 80 percent confidence level (Table 5). That is , radium in ground water is not significantly different in 1974-1976 as compared to 1966.

At best, such testing and resultant findings should be considered as indicative rather than conclusive in that only two data sets based on one-time grab samples are available and these are not from the same wells nor are the analyses by the same laboratory or with the same technique. Particularly lacking are time series data showing the variability in radium content for a given well or series of wells. On the basis of monthly sampling for 1975, Keefer (in preparation) has shown radium in the two municipal wells in the Afton, Oklahoma area to vary about 4 pCi/l annually. Similar data to show variability in central Florida ground water are lacking but if similar variability is present, temporal comparisons of ground water using the approaches demonstrated herein may be in error.

No concerted effort has been made to develop time series data for any aquifer, a deficiency which is most serious with respect to the water table and Upper Floridan aquifers commonly utilized for single family water supplies. Data collection has been inconsistent with respect to well locations and pre-analysis procedures. Data concerning the extent of mineralization and mining are also a source of error. Finally, subdividing an initially limited data base according to aquifers is a logical approach but one which reduces the degrees of freedom. Given this, subtle change in quality might well not be statistically significant and a much larger data base in terms of the number of sampling points and replicate sampling may be necessary to establish environmental quality trends. The pronounced paucity of data for the water table (36 analyses) and Upper Floridan (36 analyses), the aquifers most likely to be affected, substantiates the need for a greatly increased data base if meaningful comparisons of temporal change in quality are expected.

TABLE 5. COMPARISON OF 1966 AND 1974-1976 RADIUM-226 DATA FOR THE MINERALIZED AREA IN POLK, HARDEE, MANATEE AND HILLSBOROUGH COUNTIES*

Aquifer Considered	No. of Observations 1966	No. of Observations 1974-1976	1966 Mean	1966 S.D.	1974-1976 Mean	1974-1976 S.D.	Significant (S) or No Significant Change (NS)
Water table	6	30	16.9**	29.8	1.9	4.17	NS
U. Floridan	22	14	2.07	1.93	1.99	2.35	NS
L. Floridan	15	10	2.03	1.52	2.46	4.26	NS

* Simultaneous multiple comparisons test, $\alpha = .20$

** Discounting a maximum value of 76.0 pCi/l, the arithmetic mean is 5.1 pCi/l and no significant difference is indicated

LOCAL CONTAMINATION

Despite a consistent regional or areal pattern of apparent non-degradation of any of the three principal aquifers in or adjacent to zones of phosphate mineralization, local contamination of the water table and probably the Upper Floridan aquifers is probable but the frequency of occurrence and significance are unknown. "Local" is loosely defined as the general area of a given mine, slime, pond, processing plant, etc. and extending at most for one or two miles in any direction and 100 to 200 feet depth. Seepage from gypsum ponds and slime ponds has occurred both as percolation through berms or dams and as sudden collapse of pond substrates due to sinkhole development. Sinkhole collapse and similar acute incidents, although dramatic, are uncommon or at least not well documented in regulatory agency files. Only a few actual cases of contamination can be cited. This might indicate that no serious problems exist or it may mean that data collection to date is inadequate relative to hydrogeologic conditions and to land and water use patterns characteristic of central Florida. Obviously the issue is rather subjective but considering the magnitude, duration, and areal extent of the phosphate industry in central Florida, the near absence of historical radiochemical monitoring data and interpretive studies is regarded as a shortcoming. This lack has been documented herein. At present and for the foreseeable future, increased monitoring requirements are being levied on industry and this is laudable. It is equally critical that responsible local, regional, and state agencies have the capability to review and react to the data provided and supply additional independent assessment as necessary.

Industry maintains that the substrate beneath gypsum ponds are self sealing due to precipitation of insoluble minerals, particularly calcium fluorapatite, by neutralization of acidic effluents coming in contact with bicarbonate ground water and carbonate-rich host rocks. Opponents to such waste management practices regard such precipitation and self sealing as alleged, at best, and that unless ponds are sealed when first installed, seepage results. Effluent and gypsum associated with gypsum wastes respectively contain about 91 pCi/l and 20 pCi/g radium-226 (U.S. Environmental Protection Agency, 1973). It is reasonable to expect that wherever highly permeable limestone strata of the Hawthorn Formation are present in mined-out pits used for disposal of slimes or gypsum wastes, seepage is likely to occur. Whether such seepage has associated with it sufficient precipitation to affect sealing of solution channels, fractures, and other secondary permeability features is unanswered. By comparison, precipitation and self-sealing of earthen berms around gypsum ponds does not occur despite intergranular porosity and permeability (John Barnett, Department of Environmental Regulation, personal communication, April 13, 1977; remote sensing studies by Coker, 1971, 1972). Proof of contamination is somewhat speculative or hypothetical except in a few actual, documented cases. The writers conclude that additional field study of gypsum ponds is necessary with key emphasis on ground-water quality monitoring and development of reliable water budgets for representative ponds. This would materially assist in ending the speculation as to whether seepage is occurring.

Some consensus exists that contamination of the Floridan aquifer is local at most and that tracing of contamination from known sources is difficult to impossible (G. Parker, Geraghty and Miller, personal communication, February 25, 1977 and B. Boatwright, SWFWMD, personal communication, March 30, 1976). In part, this is attributable to two pronounced but diverse hydrogeologic characteristics of strata in the study area: 1) extensive shallow clay and silt units with poor permeability and large sorptive capacity, and 2) cavernous saturated limestones capable of diluting wastes in extremely large volumes of native ground water. Undoubtedly both characteristics serve to attenuate contamination on a local scale. Regional variability in radium content further obscures the presence and three-dimensional extent of contaminated ground water.

Perhaps the best documentation of local contamination concerns the C. F. Industries, Inc. gypsum pile failure in April 1975 as a result of sinkhole collapse (B. Boatwright, written communication, May 3, 1976). The sinkhole collapse was first sighted by Southwest Florida Water Management District (District) staff on May 17, 1975 in the course of aerial reconnaissance of the Alafia Basin. The District arranged meetings between industry and concerned public agencies and served as hydrologic advisor to the Department of Pollution

Control (DPC) which required remedial action in the form of monitoring and filling of the sinkhole in a prescribed manner. The West Central Regional Office of DPC was the lead agency in the matter. Water sampling was done by the District in cooperation with the Orlando Radiological Laboratory. Analytical methods were outlined by DPC (Tallahasee).

The stack is located about three miles southeast of Mulberry. Failure occurred when a sinkhole about 200 feet in diameter formed and allowed 90,000 cubic yards of gypsum and 4.5 million gallons of effluent to recharge the water table and underlying artesian aquifers in the period April 30 - May 19, 1975. Thereafter, discharge to the subsurface decreased as a result of gypsum plugging; however, the gypsum continued to dissolve and a more permanent plug using clay or other nonreactive material was ordered by the State Department of Pollution Control (1975). Semi-consolidated slimes were used. Aside from being acid (pH 2) and high in radium, the effluent contained high concentrations of fluoride, phosphorus, and sulfate.

Ground-water monitoring commenced April 30, 1975 with a survey of existing private and public supply wells. Data from additional wells constructed by the company specifically for head measurements and water sampling revealed the presence of primary and secondary artesian aquifers within the Hawthorn Formation and a generally northwestward flow in the upper aquifer within the vicinity of the sinkhole (based on information prepared by Richard Fountain and Associates, consultant to C. F. Industries, Inc.). Understandably, dispersal of contaminants in ground water downgradient from the sinkhole is expected and is shown in Figure 10 prepared from samples collected on July 21, 1975 (B. Boatwright, written communication, May 3, 1976). Gross alpha values east, south, and west of the sinkhole range from 3 to 16 pCi/l (mean 8.5 pCi/l) and are well below 17 and 35 pCi/l range (mean 27 pCi/l) evident in ground water on the north and northwest sides.

Prior to sinkhole collapse, recharge of the water table and deeper aquifers was associated with the presumed presence of a recharge mound having downward and outward flow components (Florida Department of Pollution Control, 1975). The State required corrective action including a monitoring plan by which C. F. Industries, Inc. would measure fluid potential (head) and water

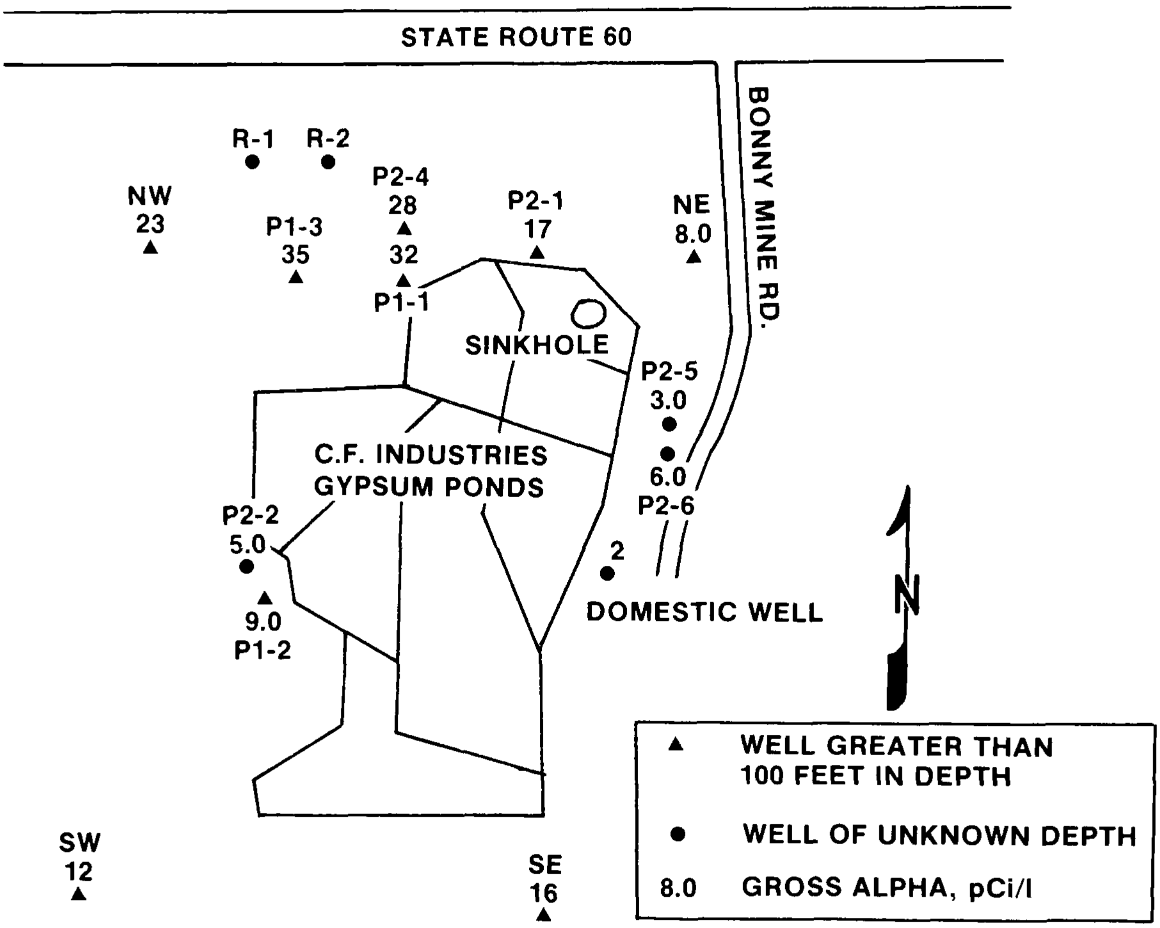


Figure 18. Gross alpha radioactivity in ground water in the vicinity of C.F. Industries, Inc. gypsum ponds.

quality in the water table (surficial sand) aquifer as well as in the upper and lower secondary artesian aquifers below.

Despite the leakage of contaminants, pronounced changes in water quality, with the exception of gross alpha are not apparent (Table 6). Rapid neutralization of acid wastes occurs and probably quickly reduces the concentration of radium, although radium data are not available to substantiate this. Reduction of the concentration by sorption is likely, particularly in areas underlain by poorly permeable strata between the ponds and the uppermost limestone units of the Floridan aquifer (G. Parker, Geraghty and Miller, Inc., personal communication, February 25, 1977). The gross alpha data indicate elevated levels of alpha-emitting radionuclides downgradient. Comparison of other radium and gross alpha data from Shearer et al. (1966) using multiple regression techniques shows a rather inconsistent relationship particularly at gross alpha levels below about 12 pCi/l. Unfortunately, at the time of writing, no radium data were available for the C. F. Industries, Inc. case.

Radium concentrations in ground water within roughly a three to six mile radius of the C. F. Industries, Inc. gypsum ponds range from 0.58 to 6.0 pCi/l. Wells completed principally in the Lower Floridan average less than 1.8 pCi/l versus 2.7 pCi/l for the Upper Floridan. Thus there appears to be little difference between aquifers. Again assuming that there is some consistent relationship between gross alpha and radium, the downgradient gross alpha values in ground water affected by the sinkhole collapse at C. F. Industries, Inc. indicate radium contamination, despite the lack of pronounced change in the other parameters.

A second case of sinkhole collapse beneath a slime pond occurred in 1968. Thermal infrared imagery revealed preferential development of sinkholes along a lineament which extended through the ponds. Despite substrate collapse, no ground-water monitoring data were collected, hence the extent of contamination is unknown (B. Boatwright, Southwest Florida Water Management District, written communication, June 6, 1977). At the Gardinier, Inc. plant south of Tampa, wells in a shallow aquifer downgradient from gypsum piles are reportedly also affected (James Pool, Department of Environmental Regulation, personal communication, April 7, 1977). At the time of writing, no additional information concerning these incidents was available to the authors.

TABLE 6. GROUND-WATER QUALITY DATA FROM MONITORING WELLS IN THE VICINITY OF THE C. F. INDUSTRIES, INC. GYPSUM POND NEAR MULBERRY

	WELL LOCATION				
	ADJACENT		DOWNGRADIENT		
Station* / Parameter**	Domestic Well	P2-2	P1-3	P1-1	P2-2
pH	8.0	8.1	8.0	7.5	8.5
Dissolved solids	269	210	218	283	167
Total solids	272	230	240	298	236
Acidity	10	10	12	44	0
Alkalinity	160	200	248	268	154
Hardness	78.7	102	124	155	77
Ca	32	12	15	21	13
Mg	14.3	17.5	21	25	10.7
SO_4	10.5	2.7	1.8	8.0	47.5
F	0.434	0.8	0.47	0.55	0.9
PO_4	0.986	0.078	0.01	0.003	0.094
Total P (as PO_4)	0.17	0.19	0.096	0.12	1.01
SiO_2	5.8	9.0	7.9	5.8	3.4
Gross alpha	<2	5	35	32	28

* Station identifiers located on Figure 10..

** Chemical analysis by Florida Department of Environmental Regulation; sampling data July 21, 1975

Water losses via seepage from three slime ponds studied by Zellars-Williams (1977) under contract to the U.S. Bureau of Mines amounted to 10 to 22 percent of the total water used for mining and beneficiation. It is reasonable to assume that seepage from gypsum ponds also enters the water table at a rate which in some locations may well equal or exceed that of slime ponds if dissolution of carbonate strata by acidic waste water occurs. Admittedly this is speculative because water budget and water quality data to ascertain if seepage from gypsum ponds occurs are notoriously lacking. To the authors' knowledge, monitoring of shallow ground water around gypsum ponds in central Florida has been limited to the sinkhole collapse incident near Mullberry. We conclude that additional monitoring studies of the effects of gypsum ponds on shallow ground-water quality are needed and that data should be collected to document changes in quality, if any, that follow mining and reclamation.

Of the 80 privately-owned wells sampled in the 1966 survey, two (wells 26 and 29) contained markedly elevated concentrations of radon (22,700 to 28,800 pCi/l), radium-226 (49 to 76 pCi/l), gross alpha (75 to 97 pCi/l), nitrate (16 to 26 mg/l), and sulfate (120 to 220 mg/l). Unfortunately well depths were not stated, hence the aquifer(s) involved is unknown. Well 26 is used for industrial water supply and is located two miles west of Agricola. The water may be naturally deteriorated insofar as water quality is highly variable in the area, particularly in the water table aquifer (B. Boatwright, SWFWMD, personal communication, March 30, 1977). Surrounding land use is predominantly rangeland. The nearest phosphate mining and processing activity is within one mile to the south. Well 29 is located on Bovis Road, two and one-half miles west of Fort Meade. Again, surrounding land is predominantly grassland with the nearest phosphate mining approximately one mile south.

Radium-226 concentrations in excess of 5 pCi/l are summarized in Table 7. Of the 122 analyses from the 1973-1976 EPA and USGS surveys, only 12 or about 10 percent exceed 5 pCi/l. The two highest values of 22 and 90 pCi/l are from a water table well in a mineralized but unmined area. This may indicate that high radium can also be a natural phenomenon and not necessarily indicative of contamination. Hutchinson (1975) noted this natural condition but gave no specific data. Wells in the nonmineralized area contain 5.2 to 14.7 pCi/l radium-226 which is considered to be a natural condition owing to the location and depth of the wells. Only two wells in the mined areas contain elevated levels of radium and these are from the Upper and Lower Floridan aquifers. No conclusion is drawn as to whether these represent natural or contaminated conditions. However, the concentrations are similar to peak values reported for wells of similar depth in mineralized, unmined areas and in nonmineralized areas.

TABLE 7. SUMMARY OF 1973-1976 RADIUM-226 DATA EXCEEDING 5 pCi/l

Well No.	Land Use	Total Depth/Cased Depth	Principal Aquifer and Radium Content, pCi/l WT	UF	LF
EP5-22	Mineralized, unmined	1801			15.3 ± 1.53
GP40-34	" "	39/34			7.7
GP95-22	" "	27/22	22,90		
EP47-6	Mineralized, mined	-/-		6.0	
GP59-4	" "	-/-			14
GP76	Mineralized	-/-	5.3		
EM14-2	"	400/90			12.1 ± 0.121
EP69-18	Nonmineralized	800/-			14.7 ± 0.147
EP69-14	"	200/99		7.3	
EP85-12	"	705/-			7.3 ± 0.073
GP89-14	"	220/-		5.2±0.052	
EP91-17	"	200/-		10.6±0.106	

Use of connector wells to dewater surficial sand and upper Hawthorn strata was initially done with little information on the radiochemical quality of ground water allowed to recharge the deeper aquifers. Recent permits for consumptive use of water issued by the Southwest Florida Water Management District require monthly water analyses of production wells and connector wells. Included in the minimum of 15 parameters for analysis is gross alpha radiation. If gross alpha exceeds 15 pCi/l analysis for radium-226 and total radium is also required. These data are reported to SWFWMD on an annual basis for production wells and monthly for connector wells. There is provision for additional testing as necessary and for administrative action if significant harm of receiving waters is indicated by the data (B. Boatwright, SWFWMD, written communication, June 6, 1977). Recent management practices emphasize stricter controls on the quality of water recharged to the Floridan aquifer system. This is worthwhile insofar as there is some difference of opinion concerning the radium content of shallow ground water. Hutchinson (1975) reported excessive radium concentrations whereas preliminary radium data supplied by industry for two mines where connector wells are in use show concentrations of 3 pCi/l or less in recharge water (B. Boatwright, written communication, June 6, 1977).

Abandonment procedures for connector wells require grouting but there is open concern by regulatory and management agencies that the rapid turnover of wells, necessitated by the pace of dewatering, stripping, and reclamation activities, results in improper abandonment (D. Guthrie, Polk County Department of Environmental Control, personal communication, June 2, 1977; B. Boatwright, SWFWMD, personal communication, June 3, 1977). There are no requirements for monitoring of ground-water quality after stripping and reclamation is completed. It is also unknown if radium increases in very shallow ground water as a result of stripping and particularly as a result of disruption of the leach zone materials and shallow aquifer. Additional geochemical or hydrogeochemical studies are recommended to determine whether shallow ground water may possibly become enriched in radium relative to pre-mining concentrations. Although available radiochemical data do not indicate this problem, the data that have been gathered are decidedly deficient for environmental monitoring purposes relative to the scale of phosphate industry activity. The water table in mined areas is poorly monitored in terms of water quality, although recent SWFWMD permits for consumptive use will require more data to close this gap.

As presently conceived, the proposed Underground Injection Control Program of the USEPA would include the practice of using connector wells to move water from the water table and Upper Floridan aquifers to the Lower Floridan aquifer. Monitoring of water quality will be a necessary part of such monitoring. Control over seepage of contaminated, radioactive gypsum pond water would not be included in these regulations. It is recommended that the use of connector wells be carefully regulated in terms of the control program and that seepage from gypsum ponds be carefully studied as to magnitude and effects to determine if corrective action is necessary.

ADEQUACY OF INDUSTRY RESPONSE TO THE DRI PROCESS

Three Development of Regional Impact applications (Borden, Inc., 1975; W.R. Grace and Co., 1975; Phillips Petroleum Co., 1975) for permission to conduct surface mining in portions of Hillsborough, Desoto, Manatee, and Hardee Counties were reviewed for their approach to prediction of radiochemical impact on ground water as a result of mining and related operations. With rare exception, qualitative statements based on the limited radiochemical data existing prior to 1975 and arguments or positions based on theory were advanced to indicate that mining would have no or little adverse impacts.

Concerning radiation, one report (Borden, Inc., 1975, p. 27-29) discusses uranium but not radium. Unsubstantiated conclusion is reached that "no problems with regard to radiochemical pollution of air or water, or of employee exposure, are anticipated...." Elsewhere (p. 29) the report mentions solution openings in the Hawthorn Formation having been discovered onsite, yet design and construction of slime ponds only incorporates seepage control measures for dams. No mention is made of the overall water balance in the ponds, despite the fact that at least 2.5 square miles of ponds will be floored in limestone, and have heads at least thirty feet above those in the Hawthorn Formation (p. 110 and exhibit 76).

Of the three DRI applications reviewed, only one, (Phillips Petroleum Co., 1975) included a preoperational health physics and environmental study including a terrestial gamma radiation survey and measurement of radioactivity concentrations (radium-226, polonium-210, lead-210, natural uranium) in air, water and vegetation. There is mention (p. 37) of plans for water quality monitoring through mining and reclamation, yet no details as to parameters, sampling locations or depths, or frequency are given. The conclusion is reached (p. 36) that no degradation of water quality in the water table aquifer should result. Comparison (p. 53-54) of waste water quality relative to that of adjacent ground water at two settling ponds indicates no deterioration as a result of high quality water in the ponds and very low seepage. Appendix A of the same report purports to estimate water quality before, during, and after mining but this is not accomplished and no radiochemical measurements of any kind are provided. Impacts of mining on the hydrologic system are addressed only in terms of flows and head declines due to dewatering or pumping. Long term (post mining and reclamation) effects and radiochemical water quality impacts are not addressed for the water table aquifer or for either of the two principal artesian aquifers.

Proposed mining of another large tract (18,685 acres total; 12,845 acres mined) in Manatee and Hillsborough Counties involves surface water quality monitoring only to ensure discharge in accordance with pertinent regulations (W.R. Grace and Co., 1975, p. 23). Although some seepage into the shallow aquifer is acknowledged (p. 24), the dissolved mineral load is considered minor and no direct discharge of liquid wastes to ground water is expected It is implicitly assumed that seepage will contain only dissolved solids, including radionuclides, although the onsite occurrence of a prominent system of collapse features is noted (p. 68). No mention of their potential role in contamination incidents is made. Monitoring of ground water will be limited to measurement of head and chloride concentration in the water supply wells tapping the Floridan aquifer.

We recognize that three DRI applications are a rather small sample and that they contain only a portion of the data reviewed and required by public agencies such as SWFWMD and the regional planning councils. Additional studies and data concerning water use and hydrology are increasingly being required as part of the permitting procedures or development orders issued subsequent to the DRI application. For example, connector wells and water supply wells must be monitored periodically, often monthly, for flow, gross alpha, and other nonradiochemical parameters. If gross alpha exceeds some limit, initially set at 2 pCi/l and more recently to 15 pCi/l, radium-226 analysis is required. In some cases a 5 pCi/l gross alpha screening level is used. If radium-226 exceeds 3 pCi/l, radium-228 must also be determined (Gordon F. Palm, private consultant, written communications, June 16, July 25, 1977 ; Barbara A. Boatwright, SWFWMD, written communication, June 6, 1977).

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APPENDIX 1. DISSOLVED RA-226 CONCENTRATION (pCi/l) IN GROUND WATER IN THE CENTRAL FLORIDA PHOSPHATE DISTRICT

Site number prefixes indicate the Agency originating the analysis: E - U.S. Environmental Protection Agency, G - U.S. Geological Survey. The second letter indicates the county: P - Polk Co., M - Manatee Co., HB - Hillsborough Co., H - Hardee Co, D-DeSoto Co. The first letter indicates the presence (M) or absence (N) of mineralization. Mineralized areas are further divided into mined and nonmined classes by use of a second letter, M or N, as appropriate. See Appendix 3. for procedure used to locate wells. Data from Irwin and Hutchinson (1976) are located by latitude and longitude only and are additionally located herein by township and range. Aquifers are defined as follows: LF - Lower Floridan aquifer, UF - Upper Floridan aquifer, WT - Water Table aquifer.

Site No. Classification	Name or Latitude and Longitude	T. R. S.	Date Sampled	Total depth / Depth cased (ft)	Aquifer	Radium-226 (pCi/l)
GP1 N	USGS (acidified sample)	26.27.11	1/03/75	362/80	LF	1.8
EP2-15 M-N	Trailer park, Lakeland	27.23.11cd	8/21/73	123/-	LF	0.77 .007
EP3-19 M-N	Trailer park, Lakeland	27.23.20cc	8/21/73	-/-	?	1.2 ± .036
EP4-20 M-N	Trailer park, Eaton	27.23.28ab	8/21/73	206/-	LF	1.7 ± .068
EP5-22 M-N	Trailer park, Lakeland	27.23.28bd	8/21/73	180/-	LF	15.3 ±1.53
EP6-21 M-N	Trailer park, Lakeland	27.23.29ad	8/21/73	135/-	LF	1.8 ± .036
EP7-7 M-N	Private well, Auburndale	27.25.21ab	8/20/73	150/-	LF	1.5 ± .045
EP8-8 N	Trailer park and camp, Haines City	27.26.24cd	8/21/73	125/-	LF	2.4 ± .072
GP8A N	USGS (acidified sample)	27.26.28	1/03/75	500/100	LF	1.8
EP9-4 N	Lake Alfred well 2	27.26.32ad	7/30/74	550/100	LF	1.8 ± .054
EP10-3 N	Lake Alfred well 1	27.26.32bd	7/30/74	550/95	LF	2.1 ± .042
GP11 N	USGS (acidified sample)	27.27.4	1/03/75	430/100	LF	.99
EP12-5 N	Haines City well no. 4	27.27.29ad	7/30/74	810/107	LF	0.51 ± .025
EP13-11 M-N	Trailer park	28.23.20bc	8/21/73	82/-	UF	2.3 ± .046
EP14-18 M-M	Central Avenue well 9, Lakeland	28.23.25ca	8/01/74	703/238	LF	0.73 ± .029
EP15-19 M-M	Well 20, Lakeland	28.23.35ab	8/01/74	-/100	UF	1.6 ± .048

GP15A-19 M-N	USGS monitor well	28.24.9dd	3/04/76	58/31	UF	1.2
GP15B M-N	USGS (acidified sample)	28.25.11	1/03/75	362/80	LF	1.6
EP18-6 M-N	Trailer park, Auburndale	28.25.17ab	8/20/73	110/-	UF	2.8 ± .056
EP19-1 M-N	Trailer park, Lakeland	28.25.18cd	8/21/74	100/-	UF	4.4 ± .044
EP20-2 N	Winterhaven well 7, Inwood Plant	28.25.24bb	7/30/74	601/186	LF	2.4 ± .048
GP20A N	USGS (acidified sample)	28.26.28	1/06/75	312/100	LF	3.8
EP21-1 N	Winterhaven well 8, 3rd street Water Plant	28.26.29dd	7/30/74	734/-	LF	1.0 ± .03
EP22-16 N	Private well, Lake Hamilton	28.27.28ac	8/21/73	320/-	LF	1.7 ± .068
EP23-6 N	Dundee well 2	28.27.28ac	7/30/74	755/152	LF	0.6 ± .018
EP24-31 M-M	Mulberry(1)	29.23.1bb	12/04/74	?/?	LF	0.13
EP25-20 M-N	Drane Airfield Rd. well 16, Lakeland	29.23.4bd	8/01/74	700/103	LF	0.92 ± .037
EP26-21 M-N	Piper Well 35, Lakeland	29.23.9ac	8/01/74	550/203	LF	0.60 ± .03
GP27-32 M-M	Mulberry(2)	29.23.13cd	12/04/74	95/53	UF	0.61
EP28-22 M-N	West Coast Grove, Cornet Road at Hwy. 60	29.23.30db	9/10/74	-/-	?	3.0 ± .09
EP29-4 M-N	Trailer park and restaurant, Mulberry	29.23.32ad	8/21/73	168/-	LF	0.19 ± .017
EP30-5 M-N	Private well, school	29.23.32ad	8/21/73	97/-	UF	0.18 ± .016
GP31-33 M-M	757156111 - 124(2)	29.24.18ba	12/04/74	120/170	UF	0.16
GP32-44 M-M	USGS monitor well	29.24.20dd	2/13/76	37/32	WT	.64
EP33-7 M-M	Hwy 7 - One mile south of air base	29.25.22cc	9/10/74	27/14	WT	<2.0
EP34-23 M-N	Multi-family supply well, Gordonville	29.25.22da	8/20/73	250/-	LF	1.2 ± .036

GP35-60A M-M	Domestic well, Bartow	29.25.23dc	12/11/74	-/-	LF	0.72
GP35B-46 N	USGS monitor well	29.26.14dc	3/18/75	22/17	WT	2.2
GP35C-34 M-N	USGS monitor well	29.26.19da	3/19/75	39/34	WT	7.7
EP37-3 N	Private well, restaurant, Lake Wales	29.27.27cd	8/22/73	405/-	LF	0.23 ± .018
EP38-9 M-M	Private well, trailer park, Mulberry	30.23.1cd	8/21/73	156/-	LF	3.5 .07
EP41-23 M-M	Mulberry well 1	30.23.12bc	9/10/74	776/78	LF	<2.0
EP42-24 M-M	Mulberry well 2	30.23.12bc	9/10/74	833/80	LF	<2.0
EP43-10 M-M	Private well, trailer park Mulberry	30.23.14aa	8/21/73	258/-	LF	1.9 ± .019
EP44-25 M-M	Mulberry Heights well	30.23.14aa	7/30/74	-/-	?	1.8 ± .054
GP45-10 M-N	Domestic well 751201422	30.23.21ca	12/10/74	80/60	UF	1.5
GP45A-2 M-M	Sand mine tailings area	30.23.35cc	12/04/74	24/21	WT	0.26
EP46-26 M-M	Industrial well	30.23.36bb	9/10/74	-/-	?	2.0
GP47-6 M-M	SWFWMD observation well-B (3)	30.24.12bb	1/08/75	-/-	UF	6.0
GP47A-3 M-M	USGS monitor well	30.24.35ca	2/26/75	22/17	UF	0.64
EP48-28 M-M	Hwy 640 E. of Hwy 555	30.24.35ab	9/10/74	-/-	?	5.5 ± .11
EP49-9 M-N	Bartow well 1, Power Plant	30.25.5cc	7/30/74	600/100	LF	2.24 .045
EP50-10 M-N	Bartow well 2, Power Plant	30.25.5cc	7/30/74	765/125	LF	2.3 ± .046
EP51-11 M-N	Bartow well 10, Water Plant	30.25.5cc	7/30/74	683/59	LF	1.4 ± .042
EP52-12 M-N	Bartow well 3	30.25.5cc	7/30/74	663/565	LF	2.6 ± .052
GP52A-42 M-N	Monitor well (4)	30.25.5dd	12/04/74	1348/1270	LF	1.2

EP53-15 M-N	Bartow well 4, Commerce Park	30.25.7cb	7/30/74	315/110	LF	1.75	.052
EP54-14 M-N	Bartow well 7, Floral Avenue	30.25.7dc	7/30/74	555/65	LF	1.1	.033
EP55-13 M-N	Bartow well 5, Jordan Pk.	30.25.8cb	7/30/74	525/93	LF	1.5	.045
GP56-5[4] M-N	Jordan Pk.	30.25.8dc	12/12/74	-/-	UF	0.96	
EP57-8 M-N	Lake Garfield	30.25.12ad	7/30/74	360/-	LF	0.54	± .027
GP57A-43 M-N	Domestic well	30.25.14	12/11/74	173/84	LF	.72	
GP58-67 M-M	Industrial well	30.25.15bc	12/05/74	772/196	LF	0.79	
GP59-4 M-M	Nursery well, Bartow	30,25.17ab	1/08/75	-/-	LF/UF	14.	
GP60-2[(4)] M-M	Private well	30.25.18ca	12/13/74	-/-	UF	0.58	
GP61-3[4] M-M	Private well	30.25.18ca	12/13/74	-/-	UF	1.5	
GP62-72 M-M	Industrial well 30A	30.25.08dd	12/12/74	700/272	LF	0.37	
GP63-73 M-M	Industrial well 46A	30.25.19aa	12/04/74	-/-	UF	1.6	
GP63A-14 N	Domestic well	30.27.4cc	12/13/76	200/99	UF	7.3	
GP65-75 M-M	Monitor well	30.25.33ca	12/04/74	-/-	WT	0.26	
GP66-76 M-M	Monitor well	30.25.33db	12/04/74	39/37	WT	0.23	
EP67-13 N	Motel and restaurant, Lake Wales	30.27.14bc	8/22/73	700/-	LF	3.4	± .068
EP68-2 N	Camp ground, Lake Wales	30.27.23dc	8/22/73	450/-	LF	3.7	± .074
GP68A-4 N	USGS monitor well	30.27.29ca	2/26/75	21/16	UF	0.20	
EP69-18 N	Trailer park, Babson	30.28.29cd	8/22/73	800/-	LF	14.7	± .147
GP69A-35 M-N	USGS monitor well	31.22.13ba	3/11/75	15/10	WT	2.0	

GP70-13 M-M	Industrial well 21	31.23.4ba	12/13/74	289/20-52	WT(5)	1.2
GP71-46A M-M	Bradley Jct.	31.23.11db	12/12/74	200/87	UF	4.5
GP71A-30 M-M	USGS monitor well	31.23.27da	2/25/75	16/11	WT	0.28
EP72-27 M-N	Domestic well at grove W. of Agrico	31.24.7ab	9/10/74	-/-	?	< 2.0
GP73-47A M-M	Bradley Jct.	31.24.15da	12/02/74	803/284	LF	1.4
EP74-29 M-N	Church, Hwy 555 and 630	31.24.26cc	9/10/74	-/-	?	< 2.0
GP74A-40 M-M	USGS monitor well	31.25.1aa	2/25/75	31/21	WT	1.8
GP74B-39 M-M	USGS monitor well	31.24.4ba	2/26/75	31/21	WT	0.46
EP76-81 M-M	Private well	31.25.20bc	12/05/75	-/-	WT	5.3
EP77-35 M-M	Hwy. 17, 3/4 mile N. of Ft. Meade	31.25.22bb	9/10/74	175/126	UF	6.2 ± .124
EP78-34 M-M	Hwy. 17, ½ mile N. of Ft. Meade	31.25.22bd	9/10/74	42/21	WT	< 2.0
EP79-36 M-M	Well in rest area on Hwy. 98 E. of Ft. Meade	31.25.25ca	9/07/74	-/-	?	< 2.0
EP81-33 M-N	Ft. Meade well 2	31.25.27ba	9/10/74	900/-	LF	< 2.0
EP82-32 M-N	Ft. Meade well 3	31.25.27ba	9/10/74	900/450	LF	< 2.0
EP83-31 M-N	Ft. Meade well 1	31.25.27ca	9/10/74	850/-	LF	< 2.0
GP83A-29 M-N	USGS monitor well	31.25.28dc	2/25/75	23/18	UF	0.32
EP84-30 M-M	2 miles W. of Ft. Meade	31.25.30dd	9/10/74	27/14	WT	< 2.0
GP84A-34 M-N	USGS monitor well	31.26.17ba	3/19/75	39/34	UF	7.7
GP84B-32 N	USGS monitor well	31.26.23bc	3/19/75	27/22	WT	0.20

GP84C-27 M-M	USGS monitor well	31.26.31ad	12/10/75	122/84	UF	0.26	
EP85-12 M-N	Camp ground, Lake Wales	31.27.10dd	8/22/73	705/-	LF	7.3	± .073
GP85A-23 M-M	USGS monitor well	32.23.13da	2/25/75	27/22	WT	0.20	
GP86-50 M-M	741156121-232 Domestic well (2)	32.24.18aa	12/05/74	-/60	WT	3.4	
GP87-51 M-M	USGS monitor well	32.24.18bb	12/13/74	-/280	LF	0.14	
GP88-93 M-M	Bowling Green	32.24.18bb	12/03/74	23/20	WT	4.4	
GP88A-19 M-M	USGS monitor well	32.24.26cb	2/26/75	23/18	WT	0.54	
GP88B-18 M-M	USGS monitor well	32.25.28cd	2/26/75	22/17	WT	0.20	
GP88C-26 M-N	USGS monitor well	32.26.2bb	3/19/75	20/15	WT	0.20	
GP88D-22 M-N	USGS monitor well	32.26.23bb	2/27/75	27/22	WT	22.	
GP88E-20 M-N	USGS monitor well	32.27.28ba	3/12/75	32/27	WT	1.4	
GP88F-1 M-N	USGS monitor well	32.27.31cc	3/12/75	51/46	UF	0.20	
EP89-14	Trailer park, Frostproof	32.28.2dc	8/22/73	220/-	UF	5.2	± .052
EP91-17	Trailer park	32.28.6bd	8/22/73	200/-	UF	10.6	± .106
EP92-37	Kelley Rd. at Hwy 27A (1 m. So. of Frostproof)	32.28.9bb	9/10/74	900/-	LF	2.2	.066
EM3-10 M-N	Domestic well	33.21.22cd	6/24/75	-/-	?	0.40	± .024
GM3A-5 M-N	USGS monitor well	33.22.1aa	2/25/75	18/8	WT	0.20	
EM4-7 M-N	Domestic well	33.22.15ba	6/24/75	93/63	WT	3.3	± .066
EM5-8 M-N	Private well, school	33.22.20dd	6/24/75	-/-	?	1.2	± .036
EM8-1 M-N	Private well, fire tower	34.21.32bc	6/24/75	-/-	?	5.1	± .051

GM10A-1 M-N	Future phosphate mining area	34.22.19dd	1/29/75	1225/750	LF	4.7	
GM10B-2 M-N	Future phosphate mining area	34.22.19dd	1/29/75	195/130	LF	0.54	
GM10C-3 M-N	Future phosphate mining area	34.22.19dd	1/29/75	30/20	WT	<.20	
GM10D-4 M-N	Future phosphate mining area	34.22.19dd	1/29/75	650/500	LF	1.4	
EM13-15 N	Domestic well	35.19.22ba	6/24/75	-/-	?	0.11	.014
EM14-2 M-N	Domestic well	35.21.5ac	6/24/75	400/90	LF	12.1	.121
EM16-16	Domestic well	36.21.4cc	6/24/75	-/-	?	1.1	.044
EM18-18 M-N	Domestic well	36.22.28da	6/24/75	260/220	LF	5.0	± .10
EM19-19 M-N	Domestic well	37.22.7cb	6/24/75	285/200	LF	4.0	.08
EM20-20 M-N	Domestic well	37.22.12cb	6/24/75	141/127	LF	3.9	± .078
EM21-21 M-N	Domestic well	37.22.17	6/24/75	-/-	?	3.7	± .074
GHB-1 M-N	275006/821442 USGS monitor well		3/17/75	31/26	WT	.20	
GHB-2 M-N	275110/820255 USGS monitor well		3/11/75	17/12	WT	4.5	
GHB-3 M-N	274033/820536 Domestic well		12/10/74	11/11	WT	1.5	
GHB-4 M-N	274216/820847 USGS monitor well		2/26/75	22/17	WT	.20	
GHB-5 M-N	274544/821442 USGS monitor well		2/25/75	22/17	WT	.32	
GHB-6 M-N	275514/820732 USGS monitor well(6)		3/11/75	23/18	WT	.20	
GHB-7 M-N	275711/820329 old irrigation well		2/25/75	22/17	WT	.94	
GHB-8 M-N	275918/820719 USGS monitor well		2/25/75	22/17	WT	.94	
GH-1 M-N	272954/814930 future phosphorus mine		12/03/74	220/84	UF	1.5	

GH-2 M-N	272954/814930 future phosphorus mine	12/03/74	32/21	WT	.20
GH-3 M-N	273516/814930 USGS monitor well	3/12/75	17/12	WT	.24
GH-4 M-N	273528/813448 USGS monitor well	3/12/75	17/12	WT	.20
GH-5 M-N	273532/814024 USGS monitor well	2/27/75	26/21	WT	.05
GH-6 M-N	273540/815216 USGS monitor well	2/25/75	17/12	WT	.20
GH-7 M-N	273541/820203	2/25/75	18/13	WT	1.9
GH-8 M-N	273659/815639	2/26/75	23/18	WT	.20
GD-1 N-N	271303/815037 near future phosphate mining area	12/03/74	320/141	UF	7.9

(1) Domestic well, water level 97 feet below land surface

(2) Domestic well along edge of phosphate mining district in a populated area

(3) Near slime pit

(4) Chemical waste injection site

(5) Uncased segment of well also open to UF and LF; drains water from surface aquifer to Floridan aquifer at phosphate mine

(6) Well surrounded by an extensive area of mining and tailings disposal

APPENDIX 2

ANALYTICAL RESULTS FROM THE 1966 FWPCA SURVEY

OF RADIUM-226 IN CENTRAL FLORIDA GROUND WATER

(tables III and IV from Shearer et al., 1966)

Table III

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
83	Bartow Well No. 3 (RAW)	650	260	1.6	-	-	-	-		
	Bartow (Treated) - Aeration, Filtration, Chlorination		80	1.4	-	-	-	-		
84	Winter Haven Wells 1 and 2 (RAW)	1 - 593 2 - 816	20	0.67	-	-	-	-		
85	Winter Haven Wells 3 and 4 (RAW)	3 - 648 4 - 640	95	0.58	1.2	0.12	0.0	0.0	2.7	2.7
86	Lake Wales Well 1, Market St. Plant (RAW)	1022	60	0.76	-	-	0.2	0.1	3.3	8.2
87	Lake Wales Well 1, Grove Ave. Plant (RAW)	1063	35	0.47	-	-	-	-		
88	Avon Park (RAW)		560	0.98	0.7	0.11	0.5	0.1	3.7	3.7
89	Sebring Franklin St. Well (RAW)	1480	140	-	0.7	0.11	0.2	0.1	0.4	3.8
90	Arcadia Well 1 (RAW)	495	480	3.3	0.9	0.52	0.6	0.1	4.9	24
	Arcadia (Treated) Aeration, Chlorination		210	2.5	-	-	-	-		

(continued)

Table III (continued)

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U ($\mu g/l$)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
91	Bowling Green at Water Tank		260	2.7	0.9	0.15	0.3	0.3	2.4	11
92	Plant City Well 3	750	150	0.77	-	-	-	-		
93	Plant City Well 2	368	360	0.00	1.2	0.06	0.1	0.0		
94	Zephyrhills	425	360	0.31	1.2	0.00	0.3	0.0	2.9	-
95	Dade City Well 1	150	305	0.00	-	-	-	-		
96	Clermont South Well	525	600	0.39	-	-	-	-		
97	Clermont Highland Well	550	720	0.29	1.8	0.04	0.1	0.0	0.8	
98	Lake Alfred Well 4 (RAW)	560	220	4.1	-	-	-	-		
	Lake Alfred (Treated) Aeration, Chlorination		50	1.8	-	-	-	-		
99	Dundee Well at City Park		560	0.0	-	-	0.0	0.0	0.7	4.3
100	Haines City Well 7	800	125	0.74	-	-	-	-		
101	Haines City Well 8	565	115	0.73	-	-	-	-		
102	Auburndale, Tampa St. Well	616	110	0.50	-	-	-	-		
103	Auburndale, Water Plant Well		85	0.53	-	-	-	-		

(continued)

Table III (continued)

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
104	Lakeland Well - 9 N. Florida Ave.	865	160	0.80	-	-	0.1	0.1		
105	Lakeland Well 22	891	260	0.84	-	-	-	-		
106	Mulberry Well 1	778	165	0.45	1.4	0.06	0.4	0.1		
107	Medula Recreation Center - North of Mulberry		320	0.23	-	-	-	-		

Table IV

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
1	H.W. 60 one mile west of Bartow, Polk County	1100	76	0.08						
2	H.W. 60 two miles west of Bartow, Polk County	551	680	1.86						
3 4	Ridge Wood Rod and Gun Club, 3 miles east of Mulberry, Polk County	170	2880	1.71	0.7	0.01	0.0	0.0	12	23
5	H.W. 548 five miles N.E. of Mulberry, Polk County	300	210	0.48						
6	H.W. 540A one-half mile south of Highlands City, Polk County	155	95	0.49						
7	1-1/2 miles north of Bartow, Polk County	200	970	0.43						
8	H.W. 60 two miles east of Bartow, Polk County	-	3060	2.18	1.5	0.74	0.0	0.1	5	27
9	H.W. 17 one and one-half miles south of Airbase, Polk County	-	1030	0.69						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
10	H.W. 17 one mile south of Airbase, Polk County	35	3550	4.5	0.9	0.38	0.6	0.1	5	13
11	H.W. 60 two miles east of Mulberry, Polk County	-	3240	0.61						
12	International Minerals Chemical Co. (Bonnie Plant), Polk County	900	860	0.40						
13	0.1 miles east of Bonnie Mine Rd. on Pebbledale Rd., Polk County	60	3890	0.12						
14 15	1/2 mile west of CCA on Pebbledale Rd., Polk County	-	990	2.35						
16	H.W. 640 at Jct. S.R. 555, Polk County	-	18,200	0.21	0.1	0.06	1.2	0.4	0.9	15
17	Bartow, 860 Herner St. Polk County	80	1010	1.19						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
18	International Minerals Chemical Co., Noralyn Plant, Polk County	92	8370	2.70	2.2	0.03	0.8	0.2	10	14
19	Homeland Rd. 1-1/2 miles north of Homeland, Polk County	98	4730	4.21						
20	One mile south of Bartow on Homeland Rd., Polk County	200	4160	1.87						
21	H.W. 17. 1-1/2 miles south of Bartow, Polk County	89	4190	1.04						
22	H.W.17. 3 miles south of Bartow, Polk County	160	5600	1.99	1.2	0.00	0.5	0.2	6	10
23	H.W. 555. One mile south of intersection of H.W. 555 and H.W. 640, Polk County	70	46,000	1.89	0.4	0.03	3.4	1.4	2	16
24	Swift Co. East Deep Well, Agricola, Florida, Polk County	800	1750	1.14						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
25	Swift Co. well B-3, one mile west of Swift Co., Polk County	1100	2000	1.78	1.4	0.04	0.3	0.0	5	16
26	Minute Maid Co., two miles west of Agricola	-	28,800	49	11	0.37	7.6	1.5	75	194
27 28	Off Bevis Rd. two miles west of Ft. Meade, Polk County	105	5780	5.22						
29	Bevis Rd., 2-1/2 miles west of Ft. Meade, Polk County	-	22,700	76	4.2	0.58	3.7	0.8	97	144
30	H.W. 17, 1/2 mile north of Ft. Meade, Polk County	97	9750	0.21						
31	H.W. 17, 1/2 mile north of Ft. Meade, Polk County	187	10,850	5.13						
32	Homeland, Polk County	105	4480	2.68						
33	Homeland, Polk County	-	4130	2.41						
34	Homeland, Polk County	88	2310	2.15						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U ($\mu g/l$)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
35	Durant Section - Durant Rd. at Turkey Creek, Hillsborough County	201	1860	1.41						
36	Intersection of H.W. 640 and Runyon Rd., Hillsborough County	90	2490	1.11						
37	H.W. 60, 6 miles west of Mulberry, Hillsborough County	150	3040	-						
38	S.R. 60 and Coronet Rd., 4-1/2 miles west of Mulberry, Polk County	200	6270	3.84	2.4	0.08	0.6	0.1	10	
39	H.W. 60, 3 miles west of Mulberry, Polk County	96	3350	0.16	-	-	0.3	0.1	1.0	0.0
40	2 miles east of Mulberry, Polk County	96	4260	0.02	-	-	0.2	0.1	0	0
41*	Kelly Rd. and H.W. 27A, 1 mile south of Frost Proof, Polk County	105	32	3.9						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
42*	H.W. 27A, 2 miles south of Frost Proof, Polk County	37	25	1.2						
43*	H.W. 27A, 3 miles north of Sebring, Highlands County	300	3830	2.3	-	-	0.2	0.2	5	13
44*	H.W. 27, 7 miles south of Sebring, Highlands County	69	23	1.42						
45*	Grassy Lake, one mile north of intersection of H.W. 27 and H.W. 70, Highlands County	46	76	5.4						
46*	H.W. 60, 2.5 miles west of Desoto-Highlands County line	-	1250	0.67						
47*	Intersection of H.W. 70 and H.W. 760 east of Arcadia, Desoto County	268	3500	8.4	0.9	0.08	0.4	0.1	20	49
48*	Brownville, Desoto County	-	1100	1.22						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
49	H.W. 17, one mile north of Wanchula, Hardee County	85	4040	0.44	0.8	0.09	0.1	0.1	2	13
50*	H.W. 39, at Crystal Springs, Pasco County	36	470	0.82						
51*	H.W. 50, 2 miles east of Winter Garden, Orange County	-	365	0.49						
52*	H.W. 439S, 1.4 miles south of H.W. 50, Orange County	-	2780	2.33	0.1	0.04	0.0	0.1	5	5
53*	H.W. 17, 2 miles south of Kissimmee, Osceola County	60 - 70	153	-						
54*	H.W. 17, 5 miles south of Kissimmee, Osceola County	90 - 115	870	2.17						
55*	H.W. 17, south of Kissimmee, Osceola County	74	1350	0.43						
56	1.5 miles west of Haines City off H.W. 92, Polk Co.	200	2340	3.9						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
57	3.5 miles east of Lakeland off H.W. 92, Polk County	162	1860	2.7						
58	3.5 miles east of Lakeland off H.W. 92, Polk County	53	2610	0.75						
59	2.5 miles east of Lakeland off H.W. 92, Polk County	150	6210							
60	H.W. 542, one mile east of Lakeland, Polk County	27	10,000	1.20	1.4	0.04	0.7	0.4	1.9	0
61	Intersection of Fields Rd. and H.W. 542 east of Lakeland, Polk County	287	3810	1.89						
62	Old Auburndale Rd. 4 miles east of Lakeland, Polk County	120	2410	3.58						
63*	H.W. 92, 1.75 miles west of Plant City, Hillsborough County	134	550	0.03						
64*	H.W. 92, 2 miles east of H.W. 579, Hillsborough County	150	240	0.02						

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
65*	Intersection of H.W. 301 and Palm River Rd., Hillsborough County	80	2020	0.46						
66*	River View, Hillsborough County	-	750	0.30						
67*	H.W. 301, .75 mile south of Alafia River Bridge, Hillsborough County	-	784	1.93						
68*	H.W. 301, 2.5 miles south of Riverview, Hillsborough County	96	630	1.73						
69	H.W. 672, 2 miles west of Picnic, Hillsborough County	187	3400	0.32	1.4	0.04	0.2	0.1	0.4	4
70	Intersection of H.W. 672 and H.W. 39 at Picnic, Hillsborough County	-	7650	0.28	0.8	0.01	0.6	0.1	6	0
71	Intersection of H.W. 674 and H.W. 39 at Ft. Lonesome, Hillsborough Co.	-	2650	0.33					0.3	0

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
72	H.W. 630, 1.7 miles west of Armour Ft. Meade, Polk County	143	11,300	7.41	1.6	0.04	1.3	0.3	12	-
73	4 miles south of Mulberry on H.W. 37, Polk County	200	5120	2.14	1.4	0.11	0.3	0.2	-	-
74	Bradley Jct., 6.5 miles south of Mulberry, Polk County	183	7330	3.90						
75	Bradley Jct., 7 miles south of Mulberry, Polk County	-	2070	0.11	1.4	0.03	0.4	0.1		
76	One mile south of Bradley Jct., Polk County	80 - 90	9460	4.32						
77	Intersection of new and old H.W. 37, Polk County	-	3300	1.31						
78	Old H.W. 37 south into Bradley Jct., Polk Co.	15	7600	19						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

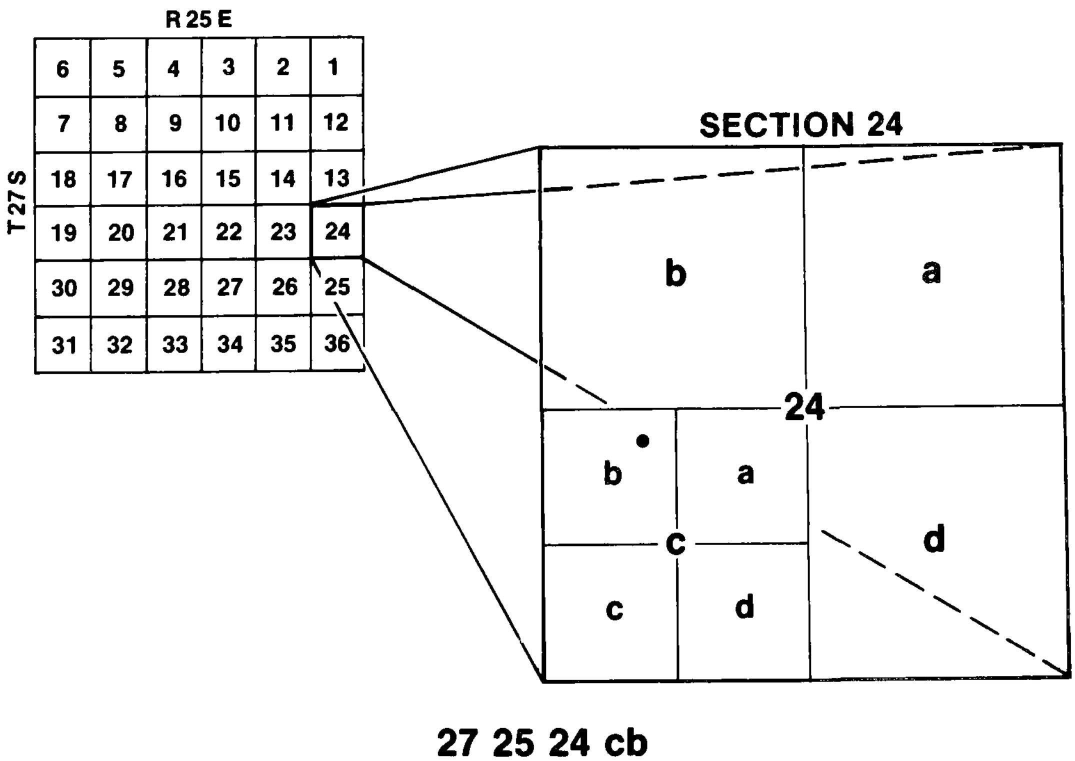
Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
79	Bradley Jct., Polk Co.	-	1480	1.31						
80	Rolling Mills, Polk County	-	6550	2.3	1.4	0.04	0.7	0.3		
81	Oak Terrace, Polk Co.	-	8680	4.6						
82	Oak Terrace, Polk Co.	-	8430	0.0						

* Considered outside of area.

APPENDIX 3. WELL NUMBERING SYSTEM

The well numbering system used in this report is based on the Federal system of land divisions. Data from the U. S. Geological Survey are located by latitude and longitude and are additionally located herein by township and range.

Under the Federal system of land divisions, a location is specified in terms of three principal parts: township (T), range (R), and section (S). In the study area, townships are measured northward at six-mile intervals from the meridian. An area of 36 square miles is defined by a given township and range and, for example, is stated as T.27S., R.25E. Within a given township there are 36 sections of one square mile each (640 acres) and numbered from 1 to 36 as shown below. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quadrants. The first letter designates the quarter section (160 acre tract) and the second letter indicates the quarter quarter section (40 acres). A well located in the NW¼ SW¼, sec.24 T.27S., R.25E. would be numbered 27.25.24cb. This is illustrated follows:



APPENDIX 4. DISSOLVED RADIUM - 226 CONCENTRATION (pCi/l) IN GROUND WATER IN SARASOTA COUNTY[1]

Site No.	Name of Well	Sample Code	T.R.S	Date Sampled	Aquifer	Dissolved Radium - 226 (pCi/l)
S1	TRAILER PARK	PW - 2993	40.19.14	2/25/76	F[2]	19.3 ± .015
S2	TRAILER PARK	PW - 2994	37.18.20	2/25/76	F	17.8 ± .014
S3	TRAILER COURT	PW - 2995	38.18.3	2/25/76	F	14.9 ± .012
S4	BUSINESS ESTABLISHMENT	PW - 2996	36.18.24	2/25/76	F	21.7 ± .015
S5	MOBILE HOME PARK	PW - 2997	38.18.10	2/25/76	F	5.4 ± .054
S6	APARTMENTS	PW - 2998	37.18.29	2/25/76	F	13.0 ± .12
S7	MOBILE HOME PARK	PW - 2999	28.18.25	2/25/76	F	15.0 ± .14
S8	FRUITVILLE ELEMENTARY SCHOOL	PW - 3000	36.18.24	2/25/76	F	12.4 ± .12
S9	VENICE CAMPGROUNDS	PW - 3001	39.20.21	2/25/76	F	12.3 ± .12
S10	ORGANIZATION OFFICE	PW - 3002	37.18.18	2/25/76	F	8.9 ± .089
S11	NOKOMIS ELEMENTARY SCHOOL	PW - 3003	39.19.6	2/25/76	F	12.1 ± .12
S12	TRAILER PARK	PW - 3004	37.18.7	2/25/76	F	10.3 ± .10
S13	TRAILER PARK	PW - 3005	37.18.13	2/25/76	F	10.1 ± .10
S14	CLUB	PW - 3006	37.17.13	2/25/76	F	4.8 ± .096
S15	ASHTON-BLISS SCHOOL	PW - 3007	37.18.11	2/25/76	F	3.5 ± .070
S16	PARK PICNIC AREA	PW - 2008	38.18.14	9/9/75	WT[3]	23.0 ± .28
S17	PARK PICNIC AREA	PW - 2009	38.18.14	9/9/75	WT	22.3 ± .27
S18	PARK PICNIC AREA	PW - 2010	38.18.14	9/9/75	WT	24.0 ± .29
S19	PARK PICNIC AREA	PW - 2011	38.18.14	9/9/75	WT	23.5 ± .28
S20	PARK PICNIC AREA	PW - 2012	38.18.14	9/9/75	WT	24.4 ± .29
S21	PARK CONCESSION STAND	PW - 2013	37.20.15	9/9/75	WT	11.8 ± .11
S22	PARK CONCESSION STAND	PW - 2014	37.20.15	9/9/75	WT	12.1 ± .11
S23	PARK CONCESSION STAND	PW - 2015	37.20.15	9/9/75	WT	14.1 ± .13
S24	PARK CONCESSION STAND	PW - 2016	37.20.15	9/9/75	WT	14.5 ± .12
S25	PARK CONCESSION STAND	PW - 2017	37.20.15	9/9/75	WT	14.1 ± .13
S26	PARK	PW - 1793	36.18.15	8/7/75	F	5.1 ± .051
S27	MOBILE HOME PARK	PW - 1796	37.18.12	8/7/75	F	6.5 ± .52

S28	CITY OF VENICE	PW - 1997	39.17.7	8/?/75	F	8.5	±.085
S29	UTILITY	PW - 1799	36.18.6	8/7/75	F	2.1	±.042
S30	PARK CONCESSION STAND	PW - 1800	37.20.15	8/7/75	WT	14.7	±.13
S31	UTILITY CO.	PW - 1801	39.19.26	8/?/75	F	10.8	±.12
S32	MOBILE HOME PARK	PW - 1802	36.18.27	8/8/75	F	8.1	±.081
S33	ENGLEWOOD WATER DISTRICT	PW - 1803	40.20.31	8/7/75	T	1.5	±.045
S34	MOBILE HOME PARK	PW - 1805	37.19.5	8/7/75	F	3.6	±.072
S35	MOBILE HOME PARK	PW - 1806	39.19.23	8/7/75	F	4.0	±.080
S36	MOBILE HOME PARK	PW - 1807	36.19.19	8/7/75	F	8.7	±.087
S37	TRAILER PARK	PW - 1808	36.18.28	8/7/75	F	6.0	±.060
S38	STATE PARK	PW - 1809	38.18.14	8/?/75	WT	7.3	±.073
S39	CITY OF SARASOTA	PW - 1810	36.20.4	8/7/75	F	4.2	±.084
S40	MOBILE HOME PARK	PW - 1812	38.18.3	8/7/75	F	22	±.15
S41	MOBILE HOME PARK	PW - 1814	38.18.25	8/?/75	F	15.3	±.14
S42	OSPREY SCHOOL	PW - 1815	38.18.3	8/7/75	--	7.3	±.073
S43	WATER COMPANY	PW - 1816	36.18.32	8/7/75	F	6.8	±.068
S44	MOBILE HOME PARK	PW - 1817	40.19.4	8/7/75	F	1.6	±.048
S45	UTILITY	PW - 1818	36.18.11	8/7/75	F	3.6	±.072
S46	UTILITY	PW - 1819	38.18.23	8/8/75	F	4.6	±.046
S47	UTILITY	PW - 1821	36.18.35	8/7/75	F	3.5	±.070
S48	PHILLIPI SHORES SCHOOL	PW - 1822	37.18.5	8/7/75	F	11.7	±.12
S49	UTILITY	PW - 1823	37.17.12	8/8/75	F	4.9	±.098

1 Data supplied by Sarasota County Health Department
2 Floridan aquifer
3 Water table aquifer

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE Effects of Phosphate Mineralization and the Phosphate Industry on Radium-226 in Ground Water of Central Florida		5. REPORT DATE October 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert F. Kaufmann, James D. Bliss		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Radiation Programs - Las Vegas Facility, U.S. Environmental Protection Agency, P. O. Box 15027, Las Vegas, Nevada 89114		10. PROGRAM ELEMENT NO.
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16. ABSTRACT Dissolved radium-226 data were statistically analyzed to characterize water quality in the water table, Upper Floridan and Lower Floridan aquifers in six counties of west central Florida where major strip mining and beneficiation of phosphate deposits is underway. Mineralization and mining have not significantly increased the dissolved radium content of native ground water, although locally elevated levels of radium in both mineralized and nonmineralized areas are naturally present. In Hillsborough, Polk, Hardee, and De Soto Counties, mean radium content of ground water beneath mined and unmined lands is 5 pCi/l or less, with maximum values on the order of 15 to 20 pCi/l occurring in unmined areas. For Sarasota and Manatee Counties, average radium content is 4 to 15 pCi/l in the water table and Floridan aquifers. Although portions of these latter two areas are mineralized, there has been no mining activity to date. Other hydrogeologic and hydrogeochemical factors such as position near the discharge portion of the ground-water flow system and increased radium solubility in water enriched in TDS are believed responsible for the elevated concentrations, particularly in the Floridan aquifer in Sarasota County. The radium-226 data base collected in the period 1966 to present is marginal for determining environmental quality trends and spatial or temporal variations because too few samples have been collected and diverse sample handling procedures affect the values produced. Recommendations for additional monitoring and technical studies are outlined to improve water and land management.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Ground water	Florida hydrology study	1808
Hydrogeology	Phosphate mining	0807
Water pollution	Radiation surveys	0808
Water quality	Environmental surveys	
Radium		
Phosphate deposits		
Statistical inference		

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